Present Status and Recent Results of Tevatron/CDF Run II

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for
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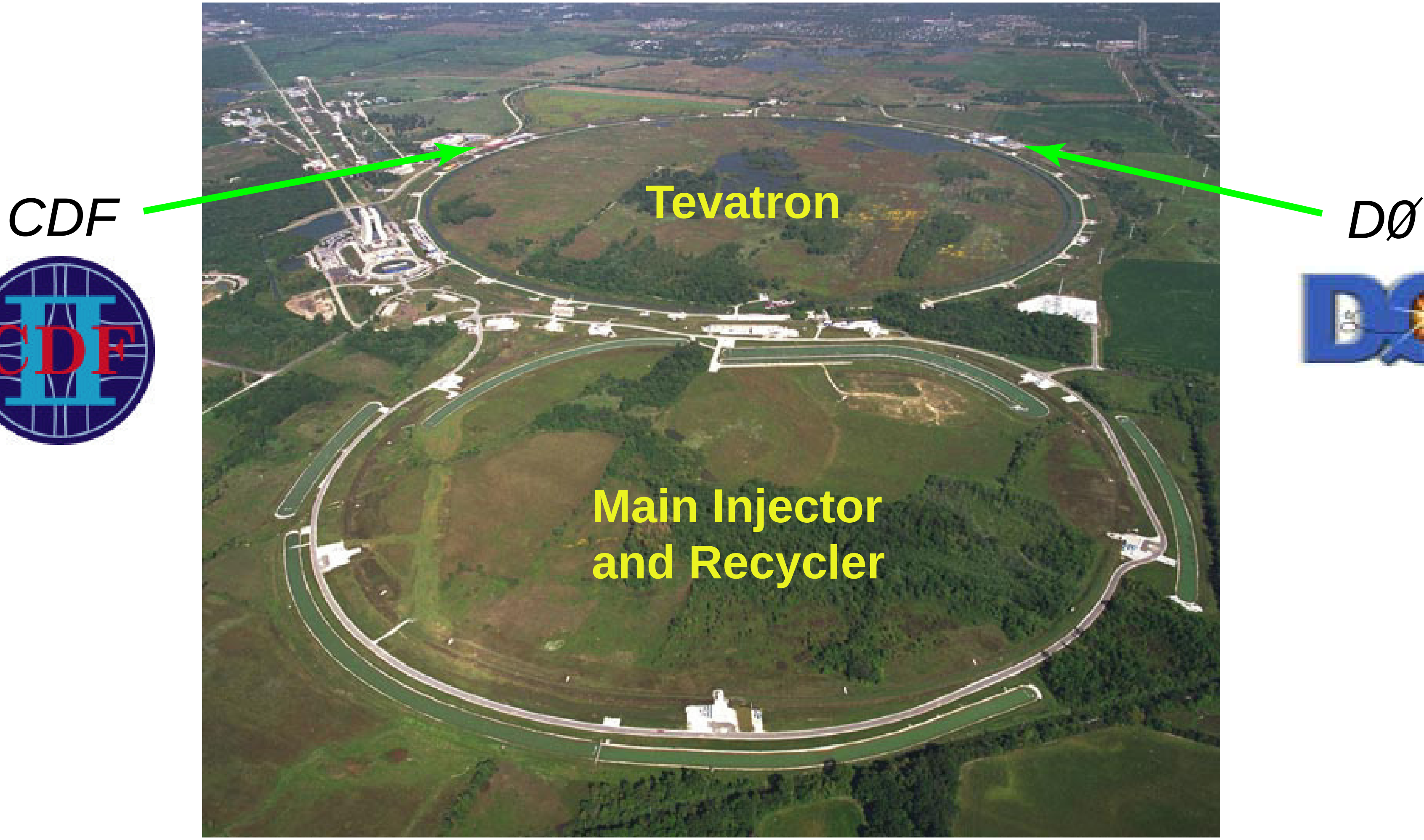
Tevatron/CDF Run II Upgrade
Present Status
Preliminary Physics Results
Prospects and Summary

Fermilab Accelerator Complex



Fermilab Accelerator Complex (2)

Tevatron Run 2 Upgrade

- Higher Energy Collisions $\sqrt{s}$ = 1.8 TeV $\rightarrow$ 1.96 TeV
- Increased number of p and $\bar{p}$ bunches 6 x 6 $\rightarrow$ 36 x 36
- Shorter bunch spacing 3.5 μs $\rightarrow$ 396 ns
- Newly built { 150 GeV Main Injector, 8 GeV Recycler }

for increasing luminosity at Tevatron

Tevatron Status

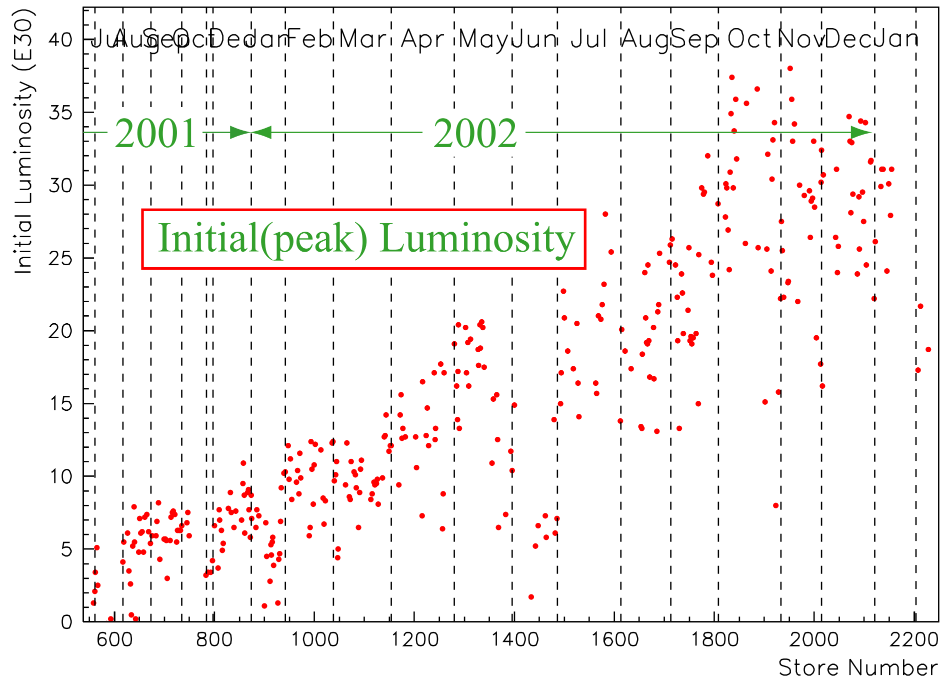
Tevatron Run 2 operation started in March 2001

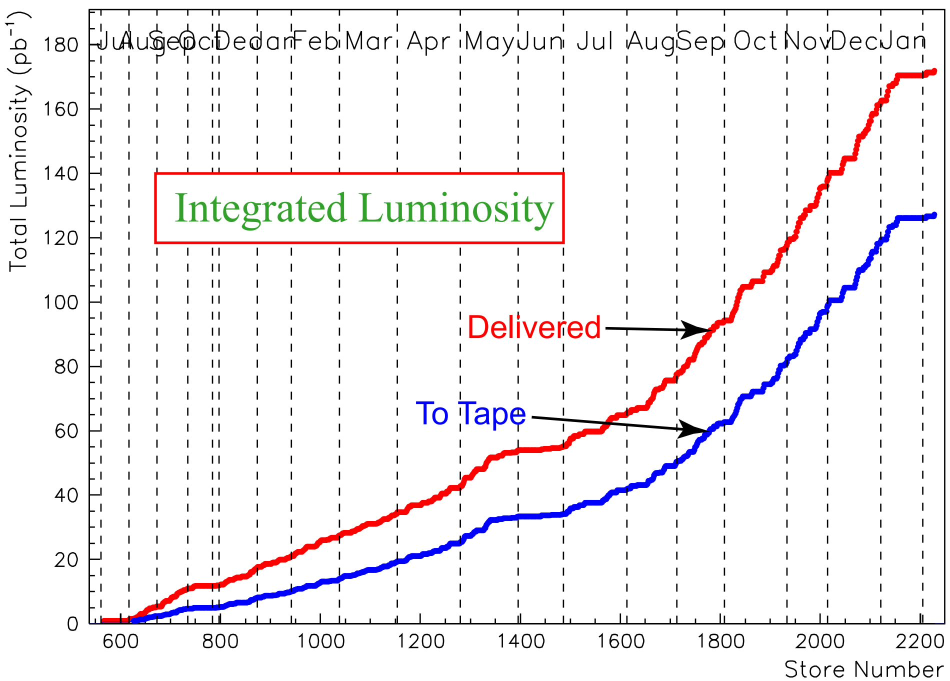
Present Status

- Now achieving typical peak luminosity of $2.5 \sim 3.5 \times 10^{31}$ cm^{-2} s^{-1}
- Run II Best : 3.8×10^{31} cm^{-2}s^{-1} on Nov. 08, 2002.
- 170 pb^{-1} delivered, 125 pb^{-1} recorded.
- 1 month shutdown from Jan. 13, 2003 → recovered on Feb. 10.

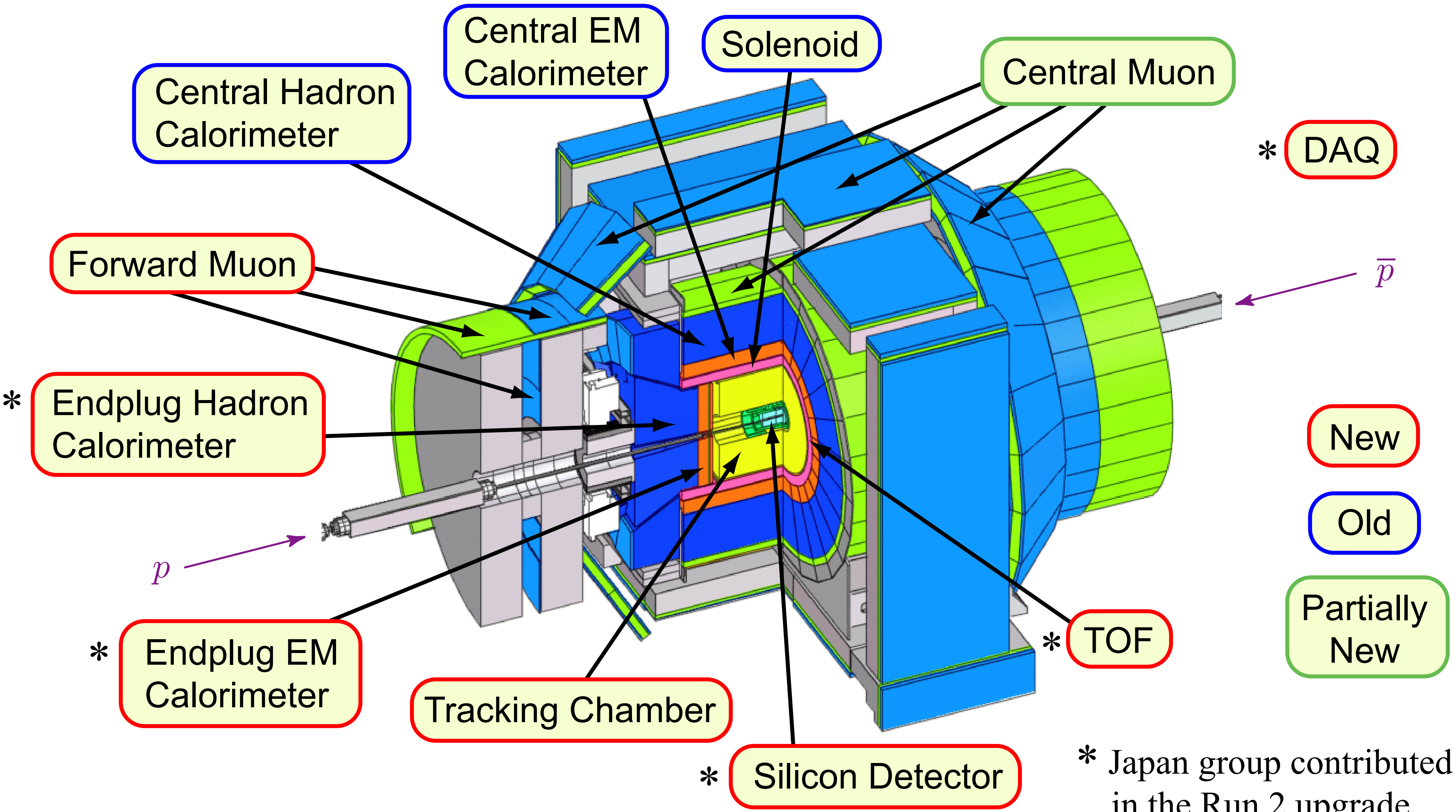
Luminosity goals for Run 2a

- Peak luminosity of 8×10^{31} cm^{-2}s^{-1}
- Integrated luminosity of 2 fb^{-1}





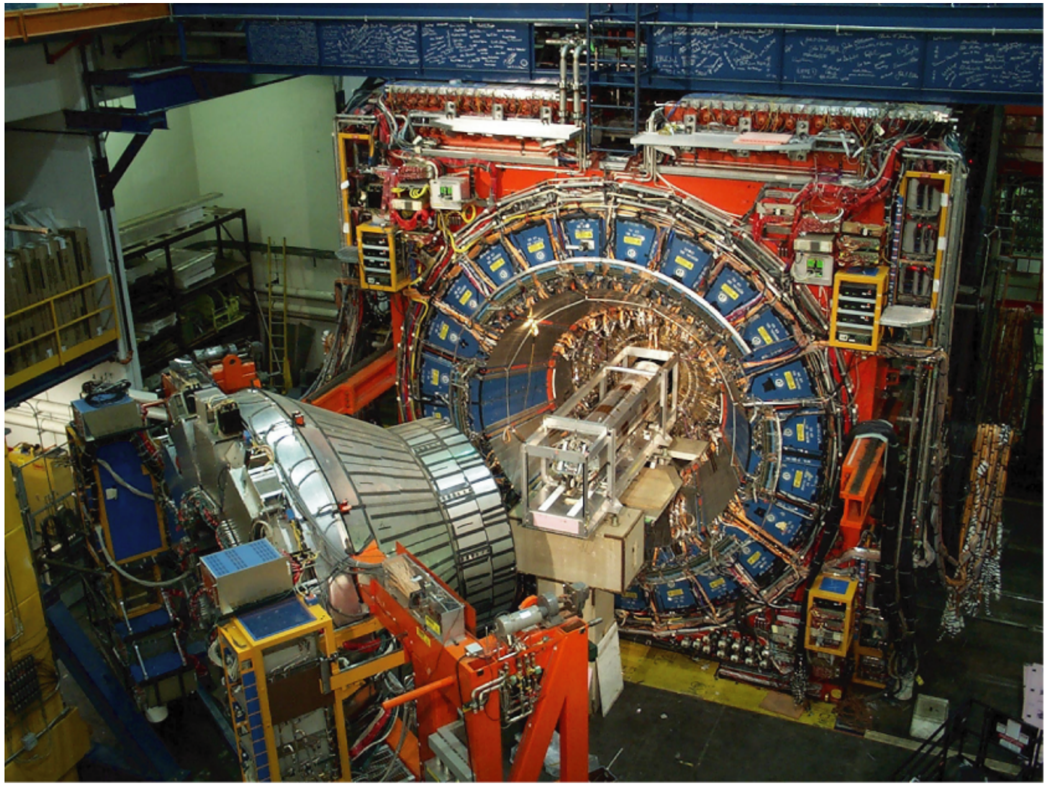
CDF II Detector



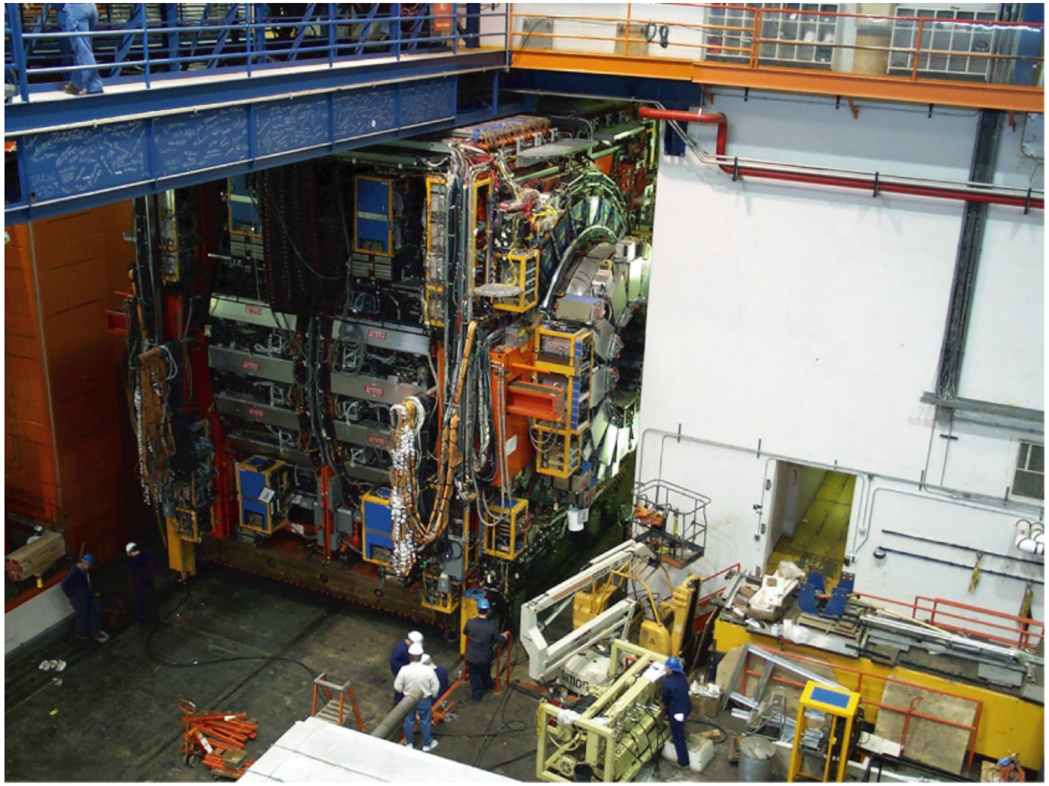
* Japan group contributed in the Run 2 upgrade

CDF II Detector (2)

Installing Silicon Detectors



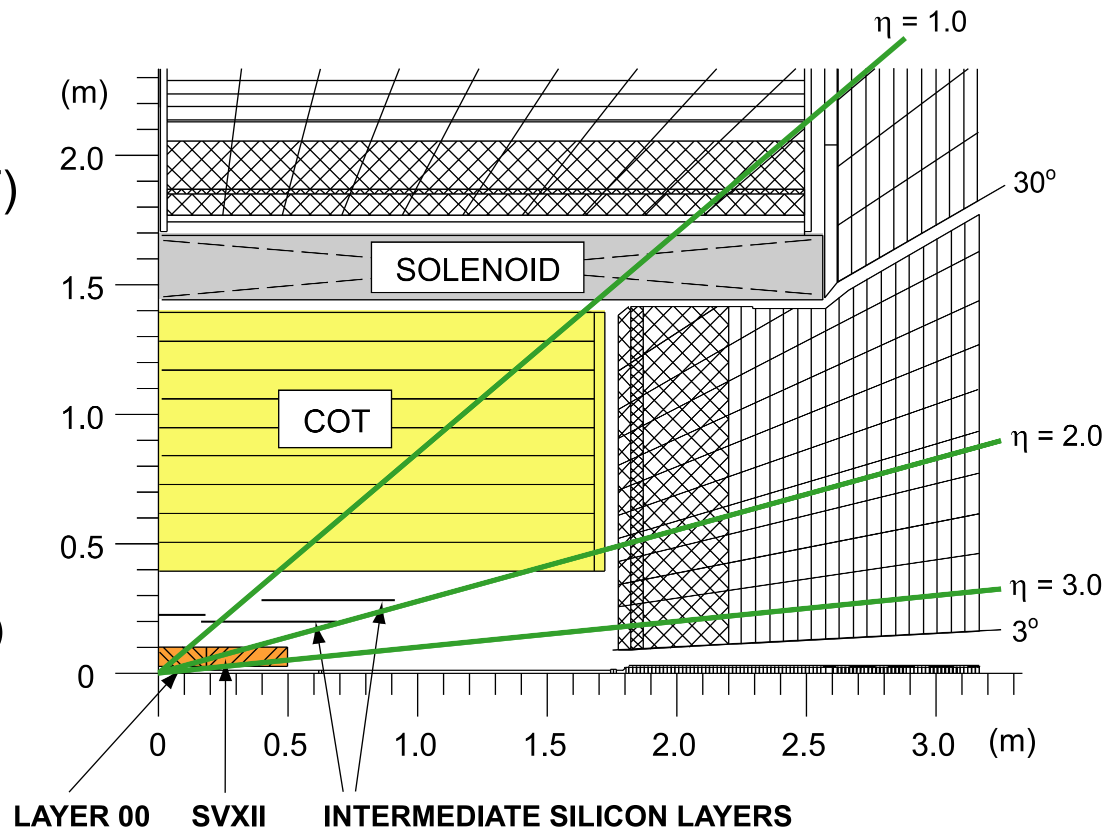
Rolling into the Collision Hall



CDF II Tracking

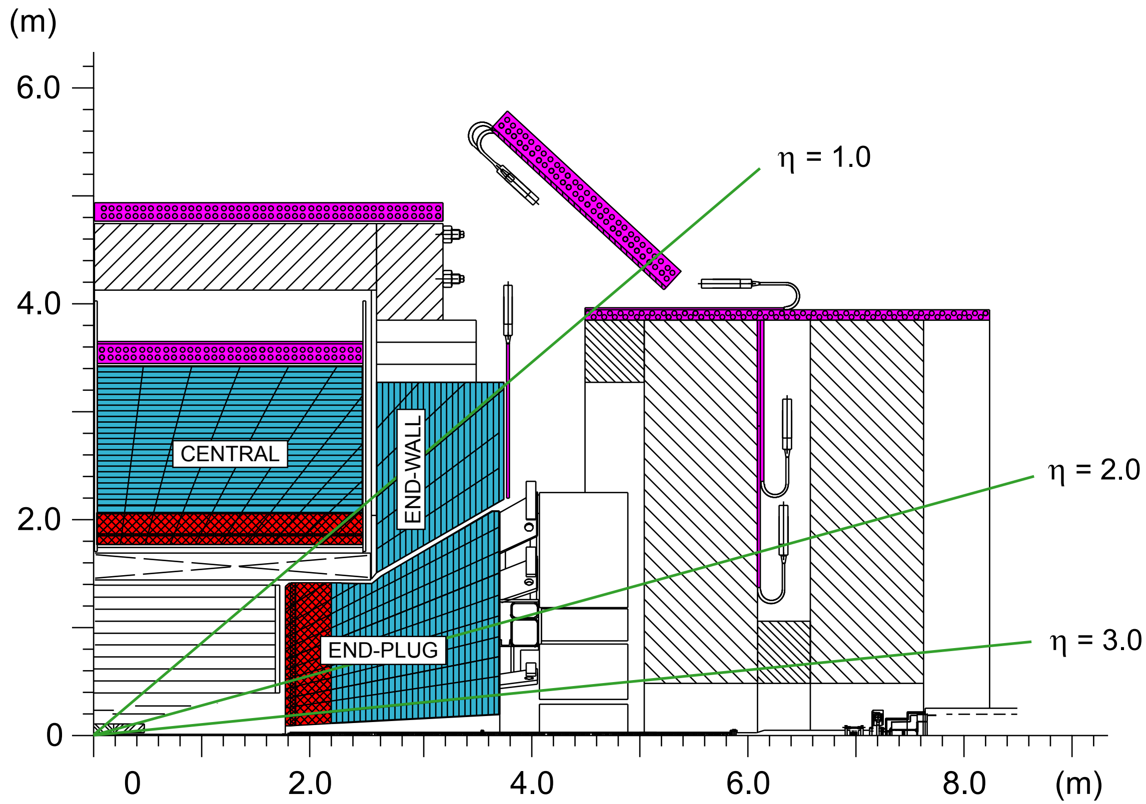
All tracking detectors inside the solenoid are new.

- Solenoid magnet (1.4T)
- Drift chamber (Central Outer Tracker, COT)
  30k sense wires
- Silicon detectors (SVXII, ISL, L00)
  8 tracking layers
  (SVXII : 5, ISL : 2, L00 : 1)
- $\delta p_T / p_T^2$ (GeV^{-1})
  - ~ 0.1% (|η|<1.0, COT+ISL+SVXII)
  - ~ 0.4% (1.0<|η|<2.0, ISL+SVXII)



CDF II Calorimeters, Muon Detectors

- Calorimeters
  - EM (Central + End-Plug)
  - Hadron (Central + End-Wall + End-Plug)
  - New End-Plug Calorimeters ($|\eta| < 3.6$)
- Muon Detectors
  - New forward detectors ($1.0 < |\eta| < 1.5$)



CDF II Trigger Overview

Level 1:

- "Hardware" trigger
- Calorimeters, COT tracks(XFT), Muons
- 50kHz accept rate (currently ~12kHz)

Level 2:

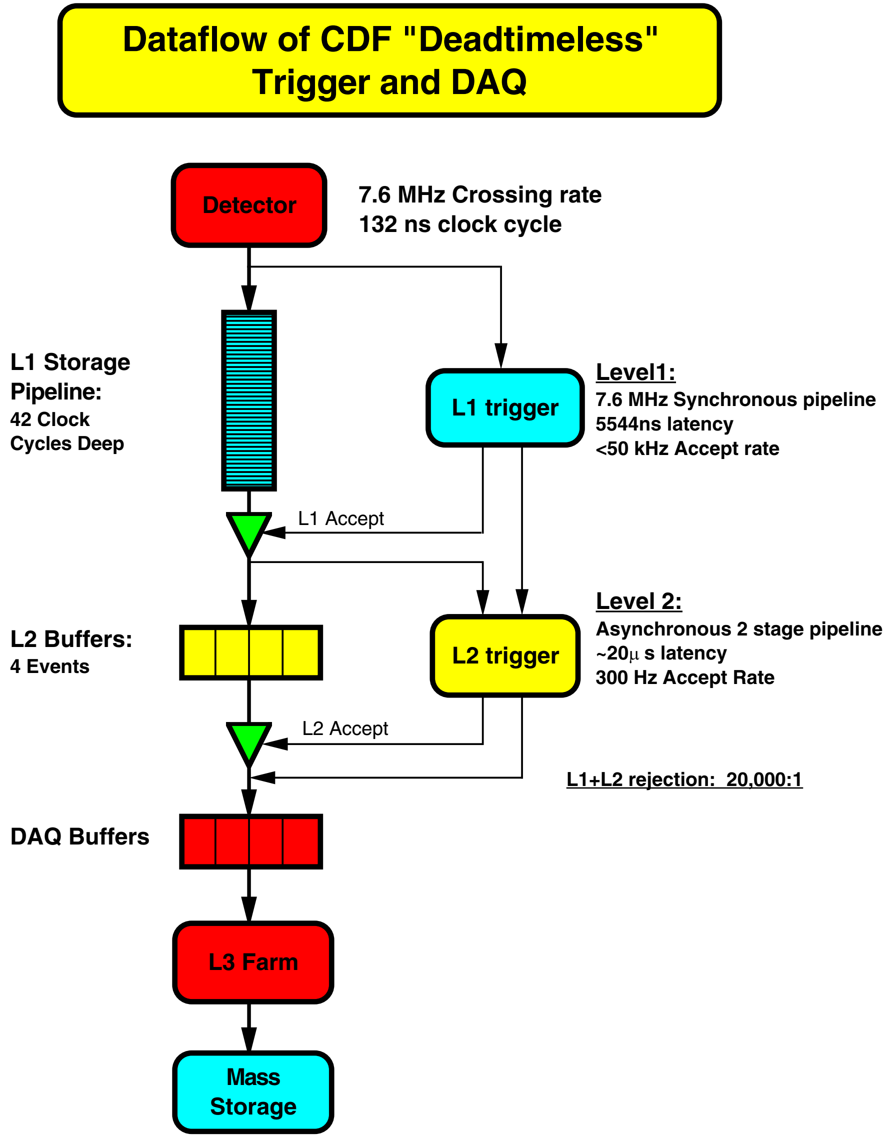
- "Mostly hardware" trigger
- Trigger algorithms run on custom Alpha boards.
- Silicon track information added (SVT)
- 300Hz accept rate (currently ~300Hz)

Level 3:

- "Software" trigger
- $\simeq$ 250 dual-CPU Linux boxes
- 50Hz accept rate (currently ~50Hz)

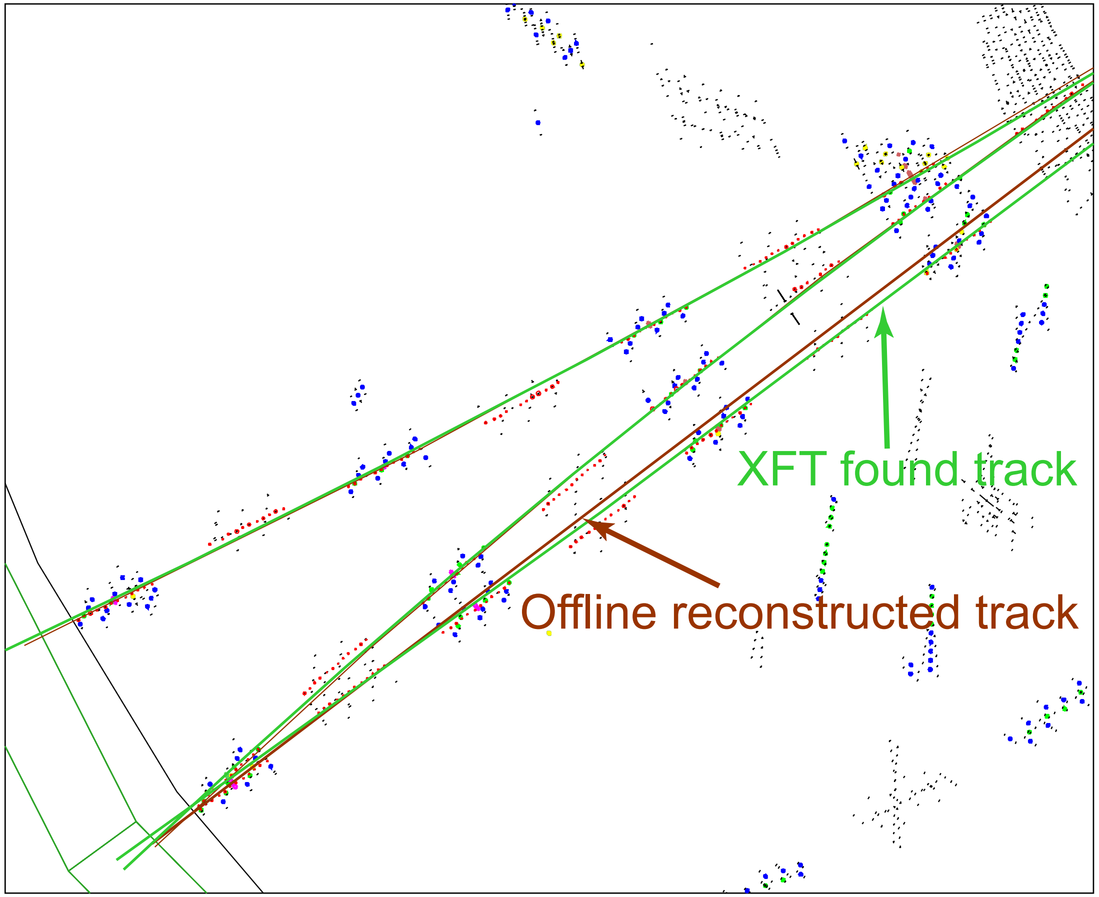
Typical event size : 250 ~ 300kB

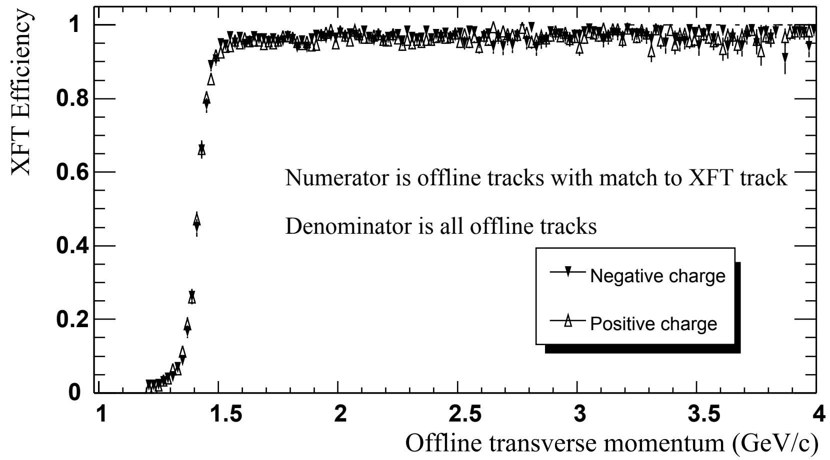
Max logging rate : 20MB/sec



XFT (eXtremely Fast Tracker)

- Track trigger on Level 1
- momentum resolution $\Delta p_T/p_T^2 = 1.65\%\ \mathrm{GeV}^{-1}$ (using data)
- angular resolution $\Delta\phi = 5.1$ mrad (using data, better than design)

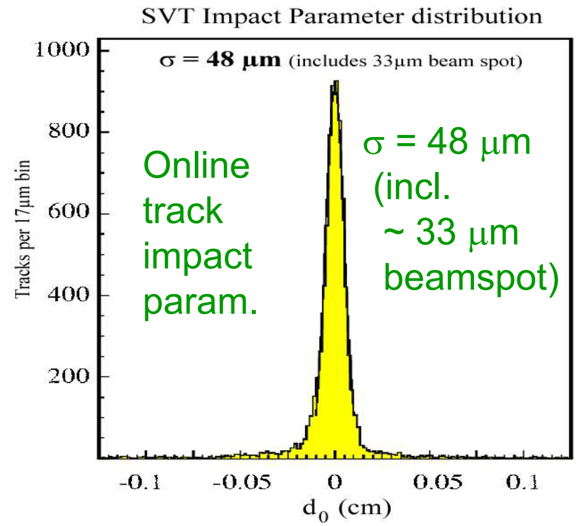


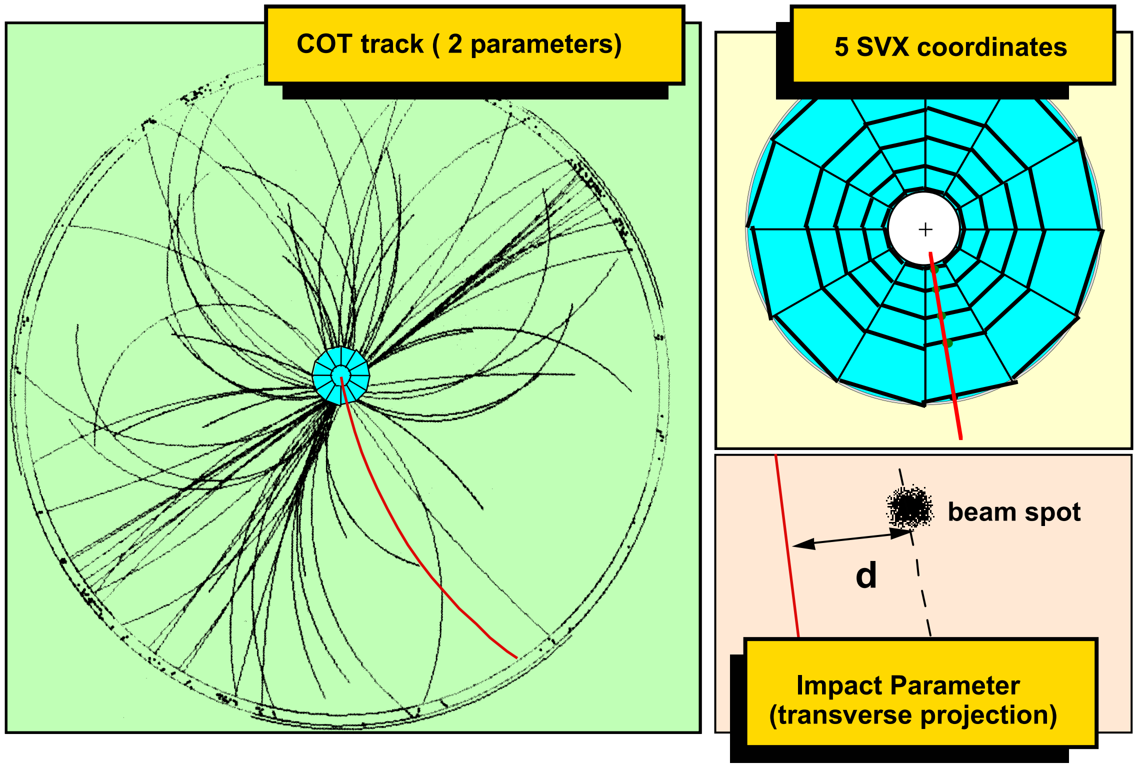


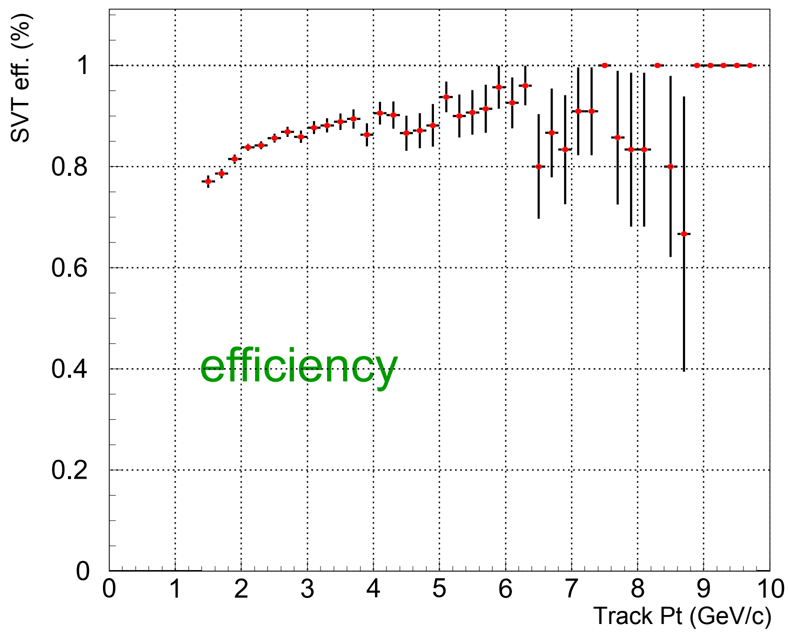
- Plateau efficiency > 96% for $p_T > 1.5$ GeV/c

Silicon Vertex Trigger (SVT)

- Track-based trigger on Level 2
- Combines COT tracks (from XFT) with silicon hits
- Allows triggering on displaced impact parameters/vertices







CDF II Collaboration

North America

United States

3 Natl. Labs
28 Universities

Canada

1 University

Totals

11 countries

58 institutes

581 physicists

Europe

Italy

1 Research Lab
6 Universities

Germany

1 University

United Kingdom

4 Universities

Russia

2 Research Labs

Spain

1 University

Switzerland

1 University

Asia

Korea

3 Universities

Taiwan

1 University

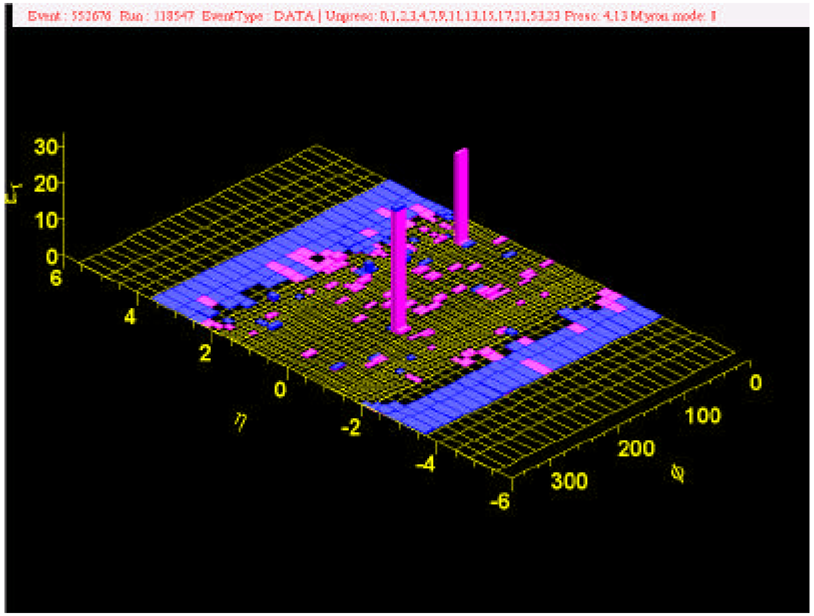
Japan

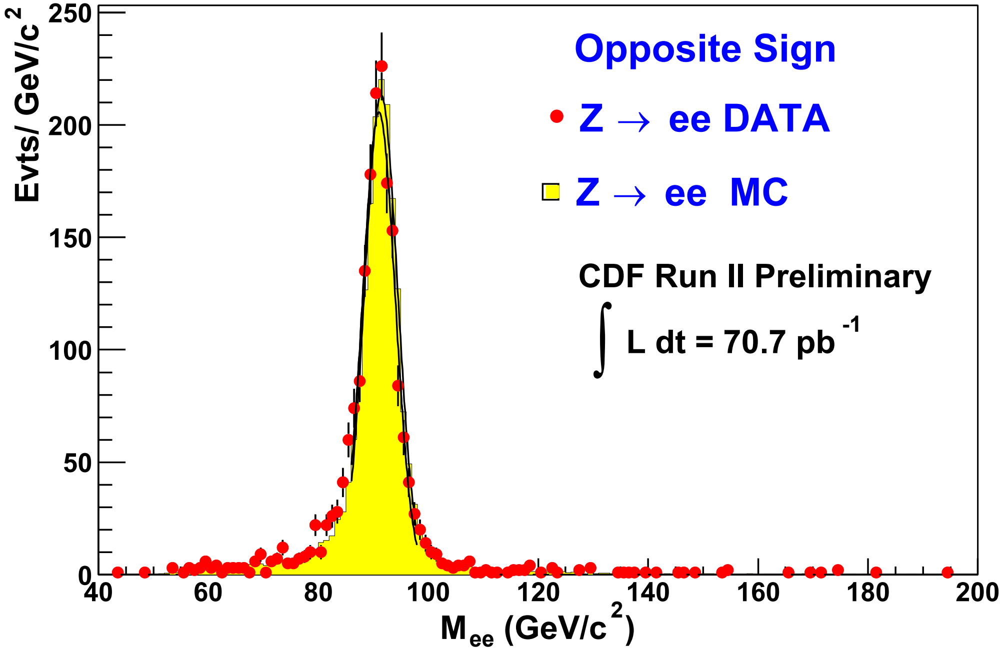
5 Universities
1 Research Lab

Univ. of Tsukuba
KEK
Waseda Univ.
Osaka City Univ.
Hiroshima Univ.
Okayama Univ.

$Z \rightarrow e\,e$

- Reconstruction of high E_T electron pairs
  (Inclusive high-E_T central electron trigger : $E_T > 18$ GeV, $P_T > 9$ GeV/c)





- $\sigma(Z)\cdot B(Z \rightarrow ee) = 269.0 \pm 6.3(\text{stat}) \pm 15.1(\text{sys}) \pm 26.9(\text{lum})$ pb
  NNLO prediction : 250.2 pb

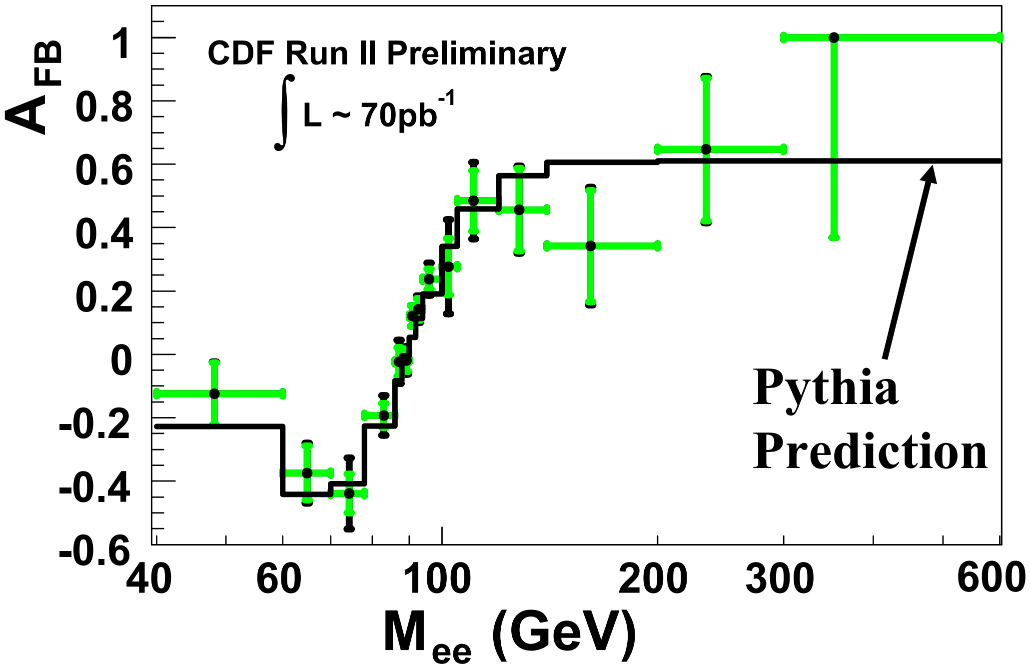
$Z \rightarrow e\, e$ (2)

Forward-backward Charge Asymmetry

$$q\bar{q} \rightarrow Z/\gamma \rightarrow e^{-} e^{+}$$

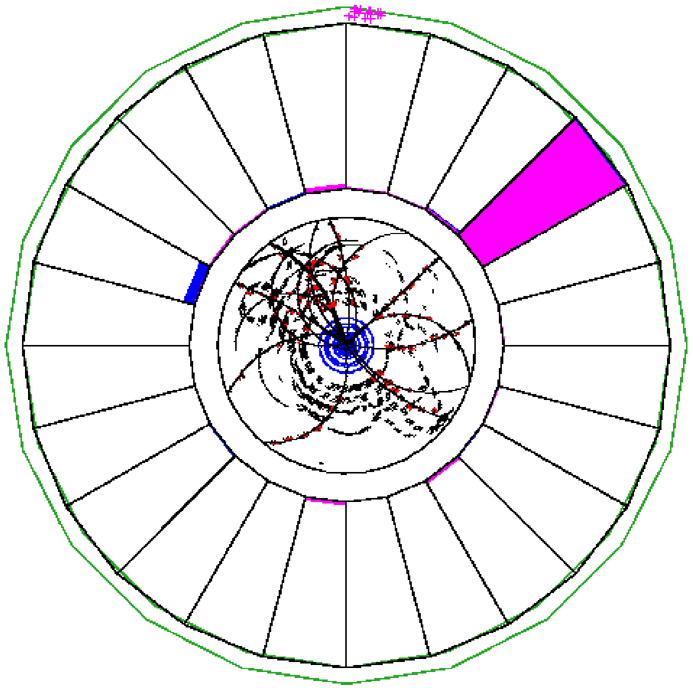
$$A_{FB} = \frac{N_F^e - N_B^e}{N_F^e + N_B^e}$$

- Probe of relative strengths of vector and axial couplings over Q^2 range
- Probe for additional heavy neutral gauge bosons

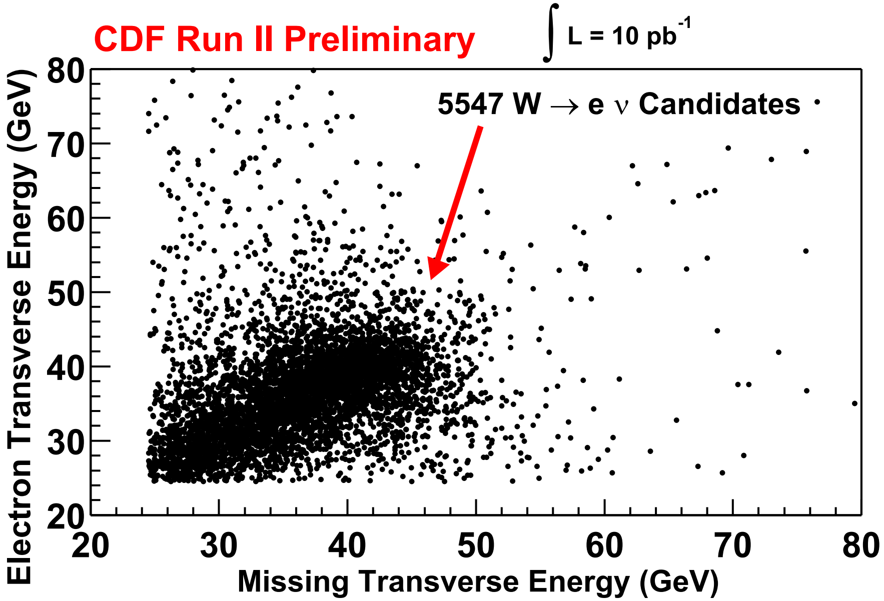


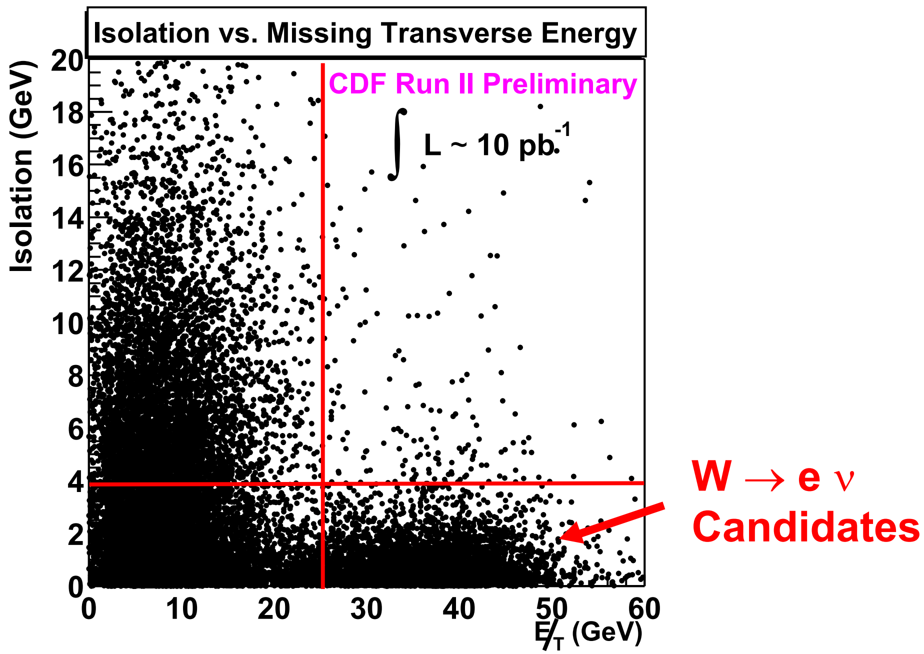
$W \to e\,\nu$

- Isolated electron
- Large E_T and $\not{E}_T$

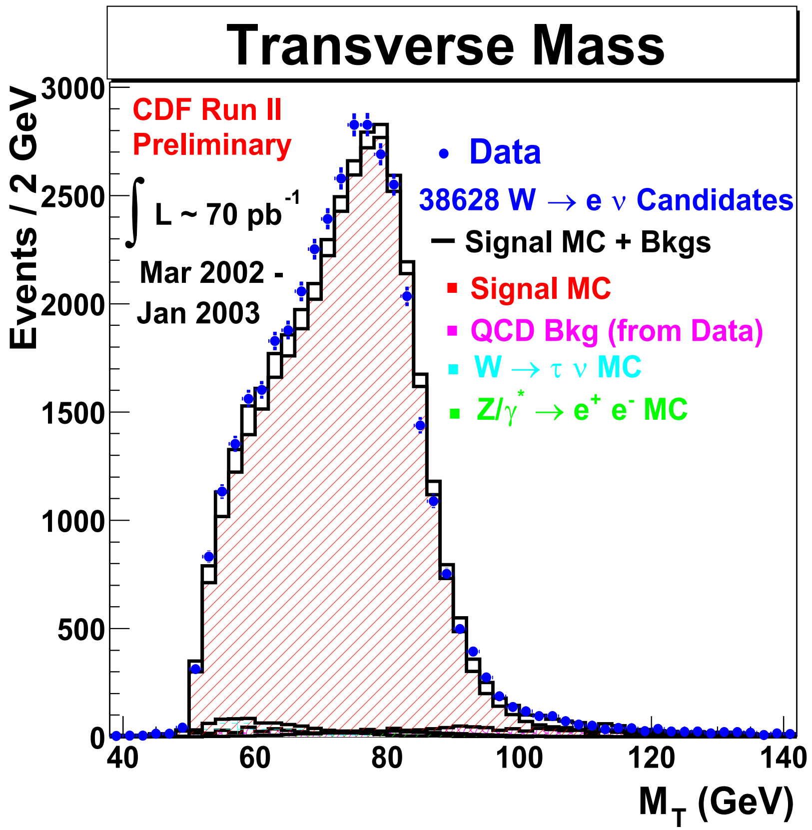


$E_T = 35$ GeV, $\not{E}_T = 38$ GeV





$W \to e\,\nu$ (2)



- Cross section measurement (preliminary)

  $\sigma(W)\cdot B(W \to e\nu)$
  $= 2.69 \pm 0.01(\text{stat}) \pm 0.09(\text{sys}) \pm 0.27(\text{lum})$ nb

  NNLO prediction : 2.73 nb ($\sqrt{s} = 1.96$TeV)

  $R = \sigma(W)\cdot B(W \to e\nu) / \sigma(Z)\cdot B(Z \to ee)$
  $= 9.93 \pm 0.24(\text{stat}) \pm 0.58(\text{sys})$

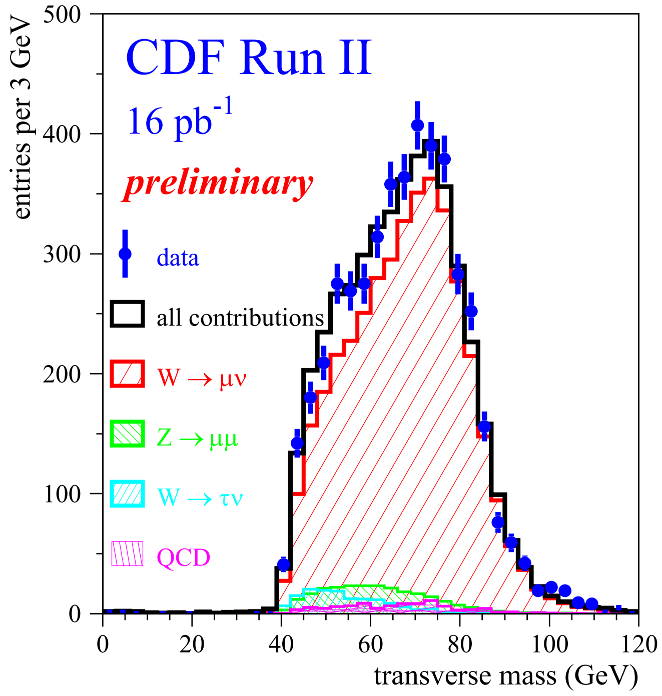
- W mass is extracted from a fit to transverse mass distribution (combined with $\mu\nu$ mode).

  $\Delta M \sim 30\text{MeV}/c^2$ with 2fb^{-1}
  (competitive with combined LEP2 result : $39\text{MeV}/c^2$)

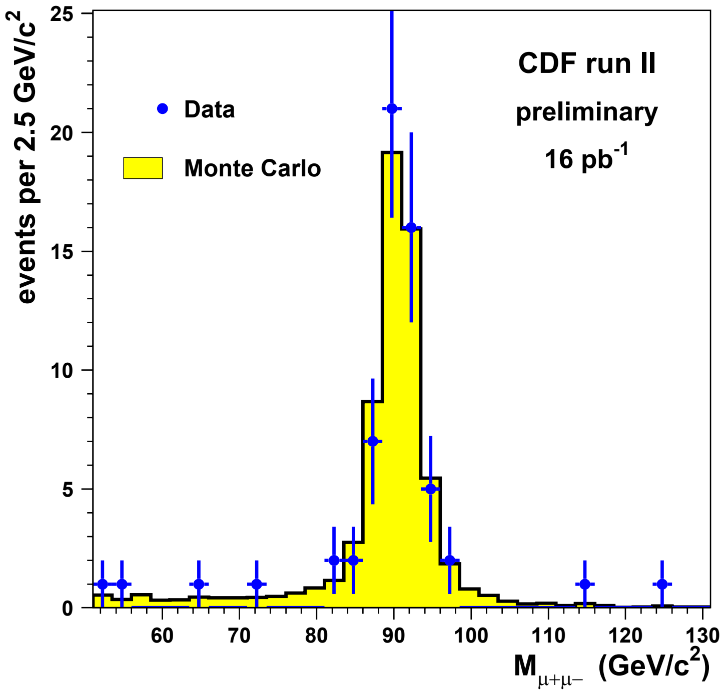
W and Z Measurements with Muons

- Inclusive high-P_T muon trigger sample ($P_T > 18$ GeV/c)

Transverse mass of W → μν



Invariant mass of Z → μμ



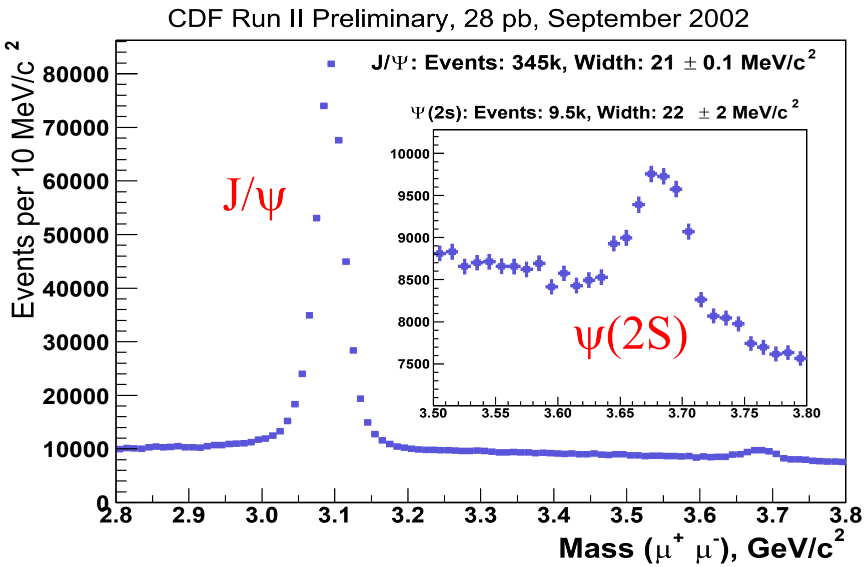
- $\sigma(W)\cdot B(W \to \mu\nu) = 2.70 \pm 0.04(\text{stat}) \pm 0.19(\text{sys}) \pm 0.27(\text{lum})$ nb
- $R = \sigma(W)\cdot B(W \to \mu\nu) / \sigma(Z)\cdot B(Z \to \mu\mu) = 13.66 \pm 1.94(\text{stat})^{+0.14}_{-0.13}(\text{sys})$

(Run 2 preliminary)

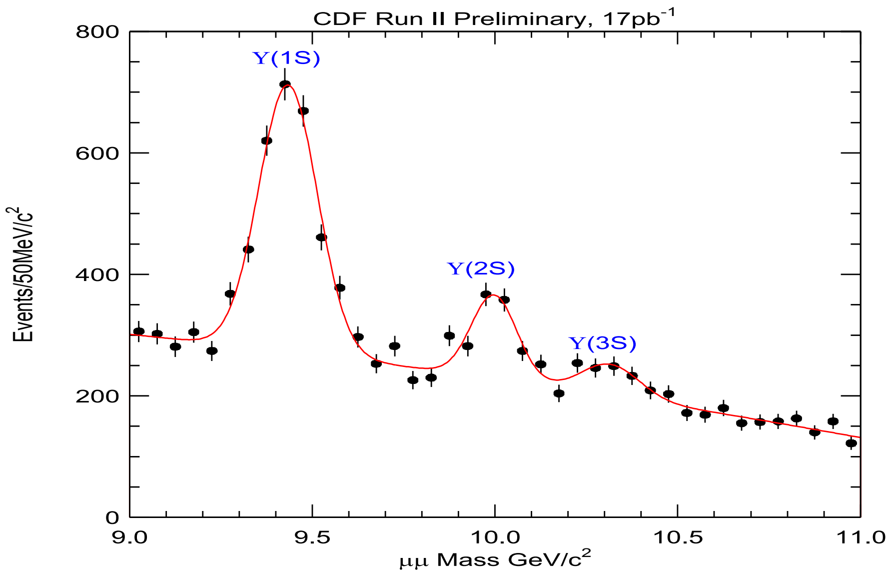
Measurements with Low p_T Muons

- Di-muon trigger sample ($P_T > 1.5$ GeV/c)

$J/\psi \rightarrow \mu\mu$



$\Upsilon \rightarrow \mu\mu$



- Large sample of J/ψ is a good tool of physics analysis and tracking calibration.

Measurements of B Masses

- Cross check of tracking calibration using J/ψ decay channels

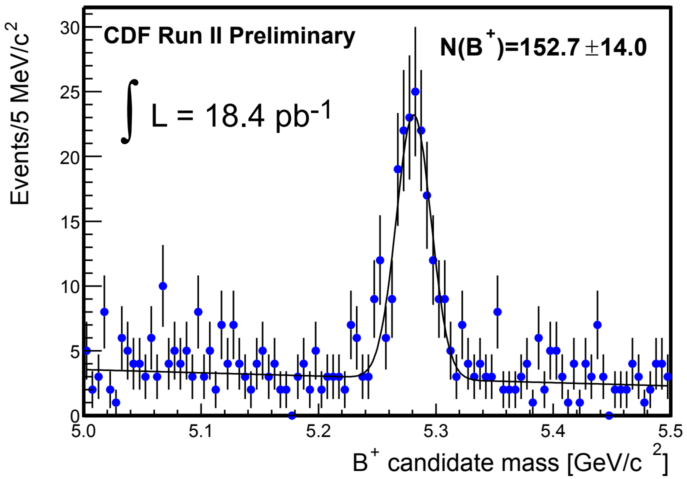
$$m(B^+) = 5280.6 \pm 1.7(\text{stat}) \pm 1.1(\text{sys})\ \text{MeV}/c^2 \quad (\text{PDG}: 5279.0 \pm 0.5\ \text{MeV}/c^2)$$

$$m(B^0) = 5279.8 \pm 1.9(\text{stat}) \pm 1.4(\text{sys})\ \text{MeV}/c^2 \quad (\text{PDG}: 5279.4 \pm 0.5\ \text{MeV}/c^2)$$

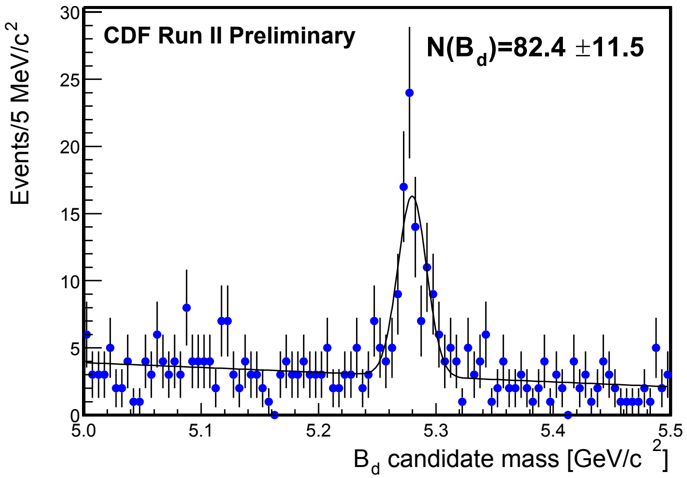
Starting to be competitive . . .

$$m(B_S^0) = 5360.3 \pm 3.8(\text{stat})\ {}^{+2.1}_{-2.9}(\text{sys})\ \text{MeV}/c^2 \quad (\text{PDG}: 5369.6 \pm 2.4\ \text{MeV}/c^2)$$

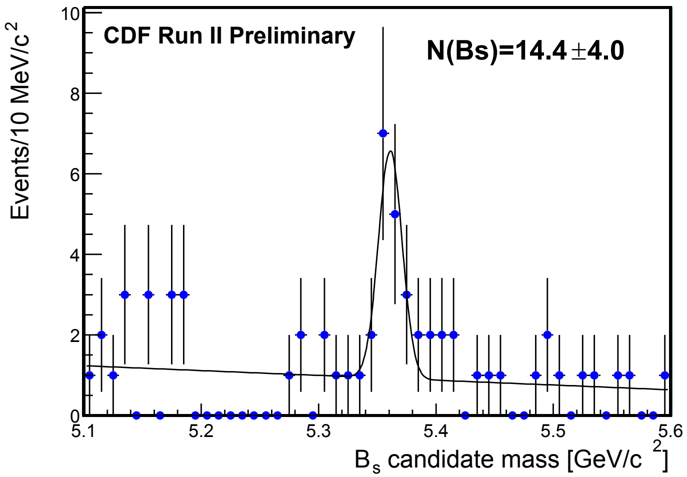
$B^+ \rightarrow J/\psi\, K^+$



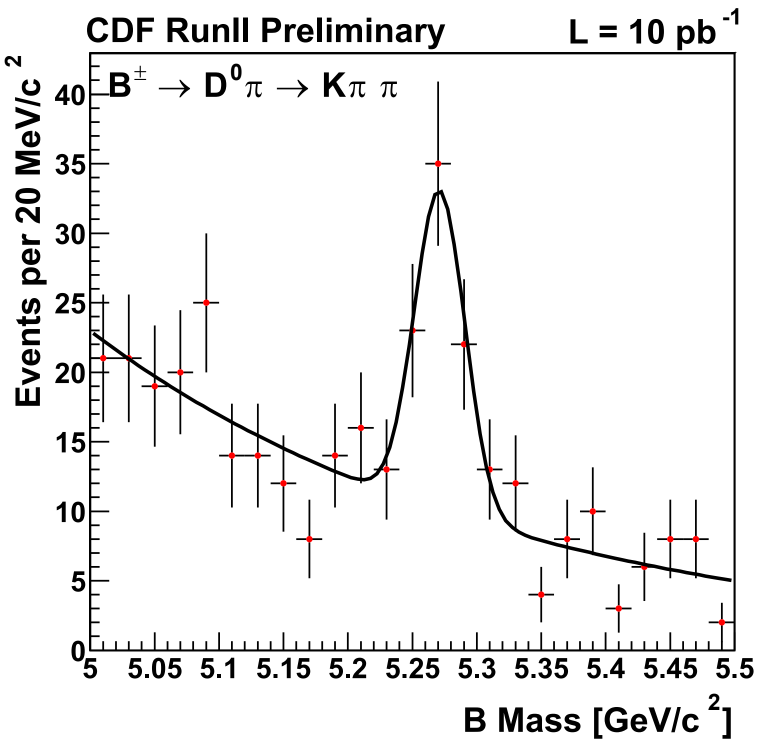
$B^0 \rightarrow J/\psi\, K^{*0}$

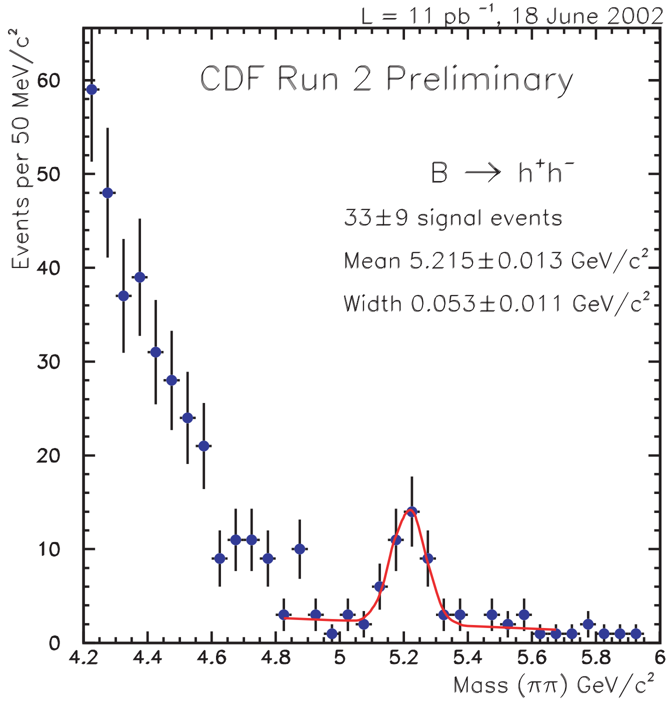


$B_S^0 \rightarrow J/\psi\, \phi$



Fully Hadronic B Signals with the SVT Trigger

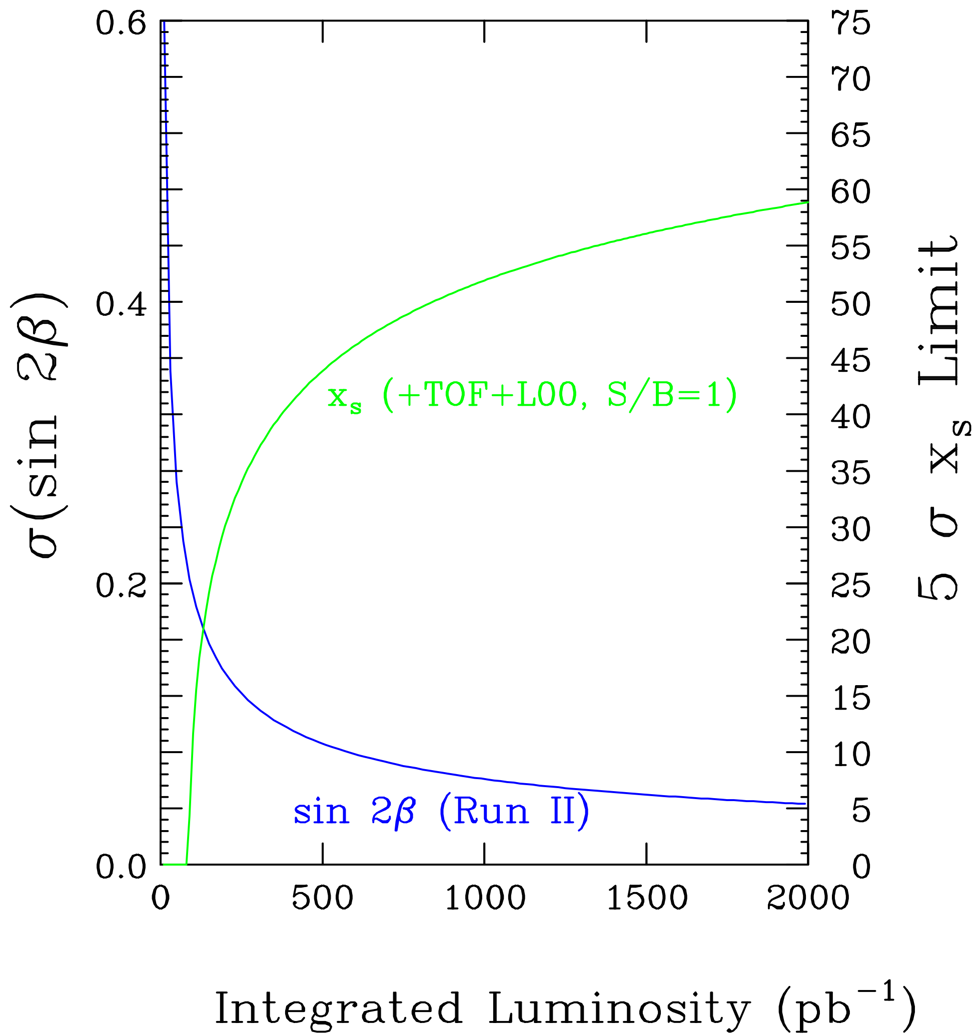




- Hadronic triggers are working !!
- First step to find $B_s^0 \to D_s^- \pi^+$, $D_s^- \to \phi\,\pi^-$, $\phi \to K^+K^-$

towards B_s^0 - $\bar{B}_s^0$ mixing

B Physics Projections



- measurement of sin2β

  $B^0 \to J/\psi\ K_S$

  $\sigma(\sin 2\beta) \sim 0.05$ with 2 fb^{-1}

- B_s^0 - $\bar{B}_s^0$ mixing (⇐ unique at Tevatron)

  $B_s^0 \to D_s\,\pi,\ \ D_s\,\pi\pi\pi$

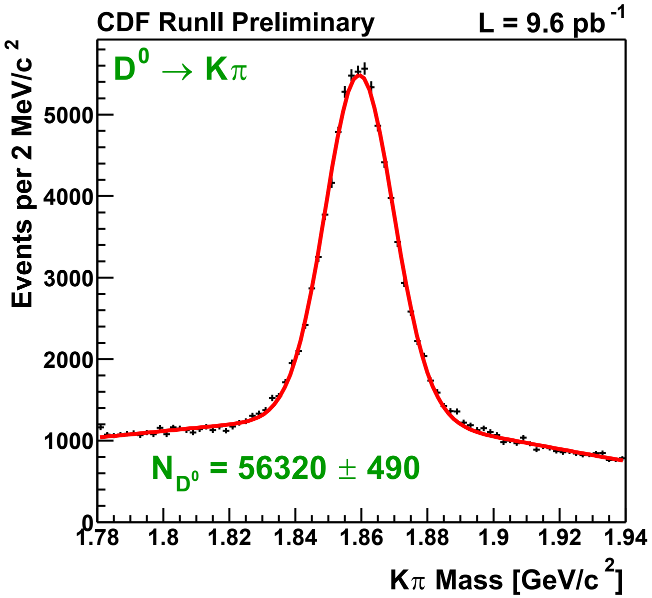
  CDF sensitivity at 5σ for $x_s < 60$
  ($x_s = \Delta m_s / \Gamma_s$)

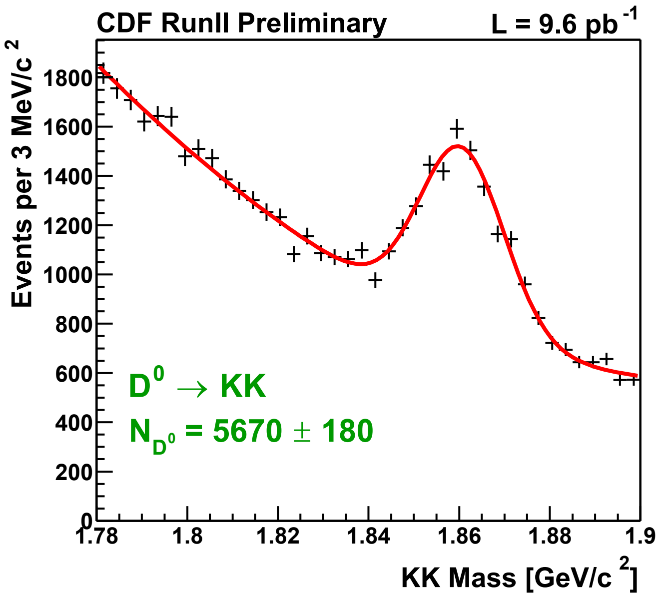
  Latest LEP limit : $x_s > 21$ ($\Delta m_s > 14.4$ ps^{-1})

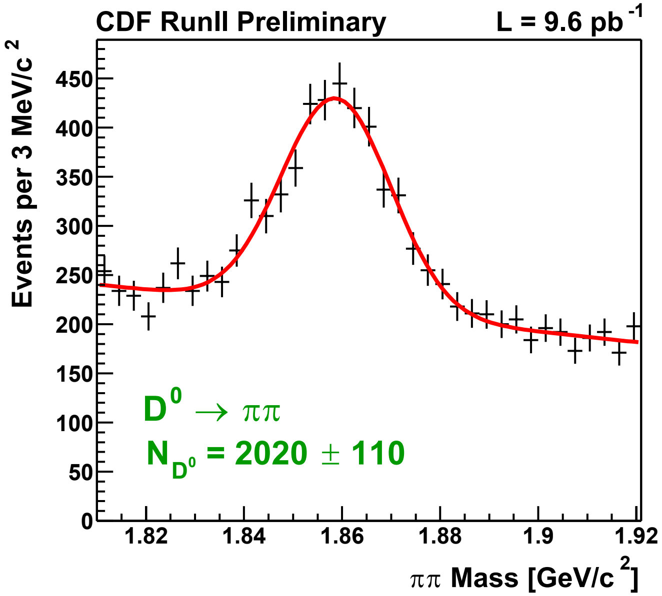
  SM expectation : $x_s < 35$

Measurements of Charm Mesons

- SVT trigger collects charm events as well as bottom events.







- Ratios of Cabibbo suppressed D^0 decays

$$\Gamma(D^0 \to KK)/\Gamma(D^0 \to K\pi) = 11.17 \pm 0.48(\text{stat}) \pm 0.98(\text{sys})\ \% \quad (\text{PDG}: 10.83 \pm 0.27\ \%)$$
$$\Gamma(D^0 \to \pi\,\pi)/\Gamma(D^0 \to K\pi) = 3.37 \pm 0.20(\text{stat}) \pm 0.16(\text{sys})\ \% \quad (\text{PDG}: 3.76 \pm 0.17\ \%)$$

already competitive with CLEO2 results
starting to be competitive with PDG averages

Measurements of Charm Mesons (2)

- $D_s^{\pm}$ - $D^{\pm}$ mass difference

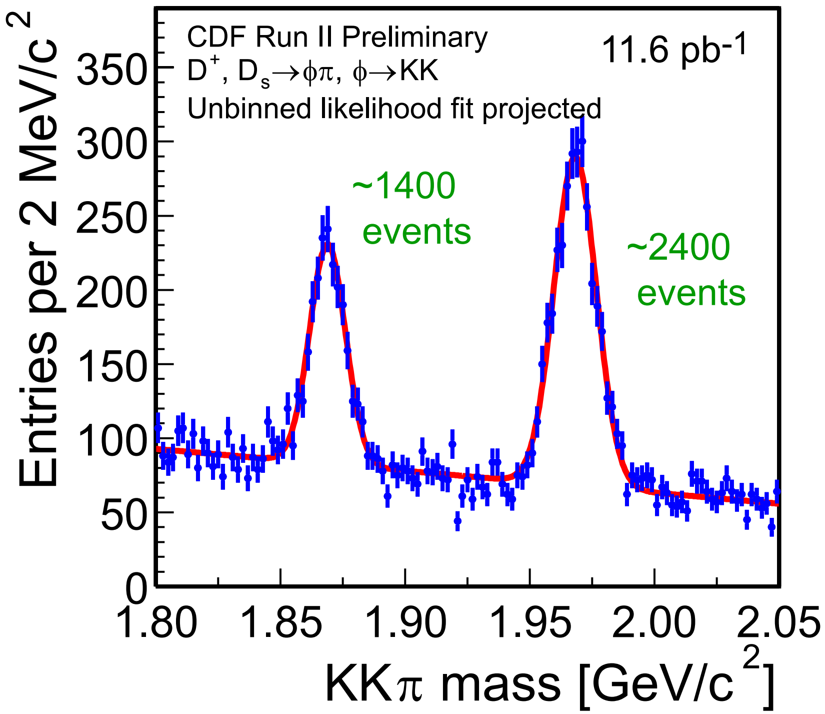
  Reconstructed $D_s^{\pm}(D^{\pm}) \to \phi\,\pi$ ($\phi \to KK$)

  $M(D_s^{\pm}) - M(D^{\pm})$

  $= 99.28 \pm 0.43(\text{stat}) \pm 0.27(\text{sys})$ MeV/c^2

  (PDG average : 99.2 ± 0.5 MeV/c^2)

  already competitive

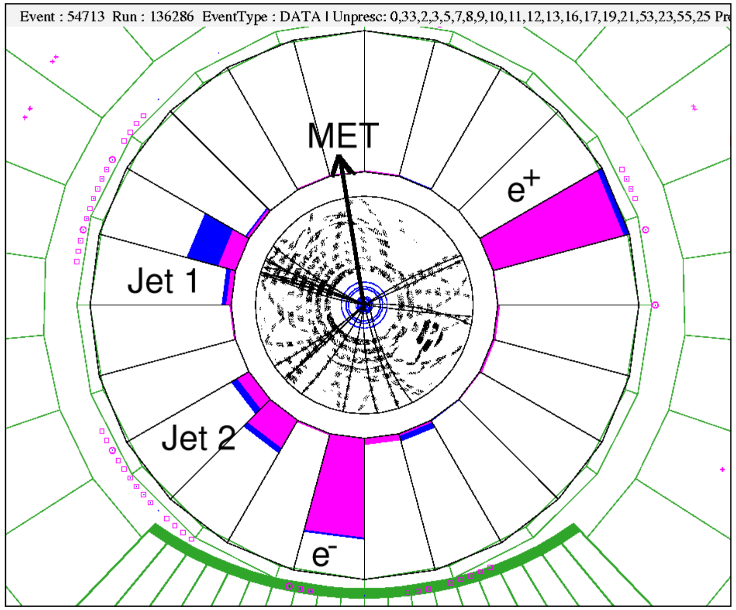


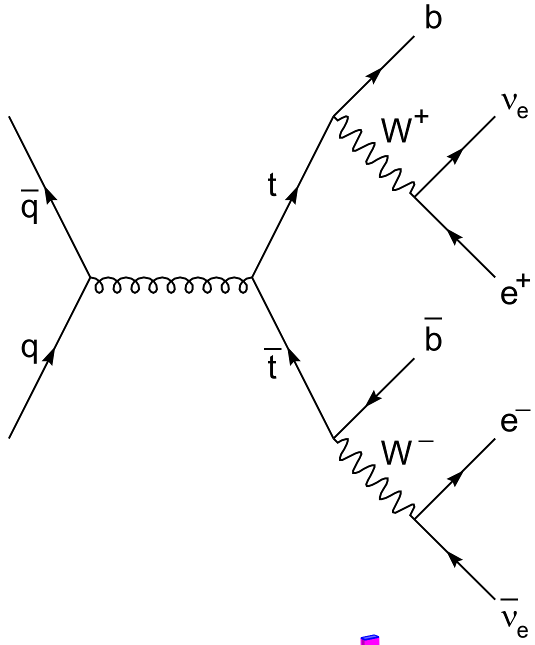
- Expect O(10^7) fully reconstructed D meson decays in 2 fb^{-1}

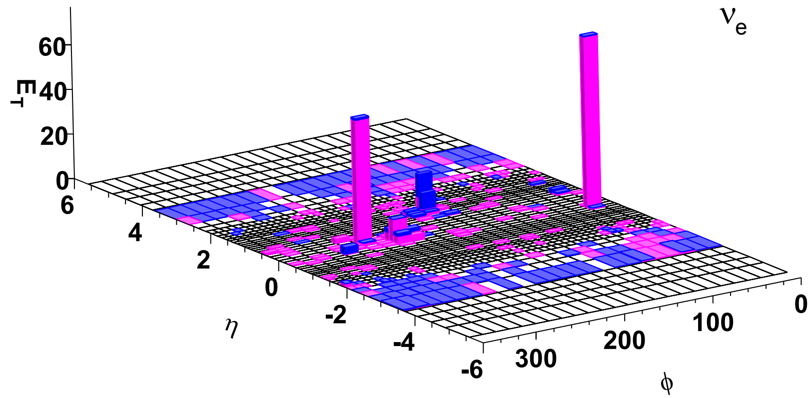
  Foresee a quite interesting charm physics program

  CP asymmetries and mixing in D sector, rare decays, . . .

Top Event Candidate





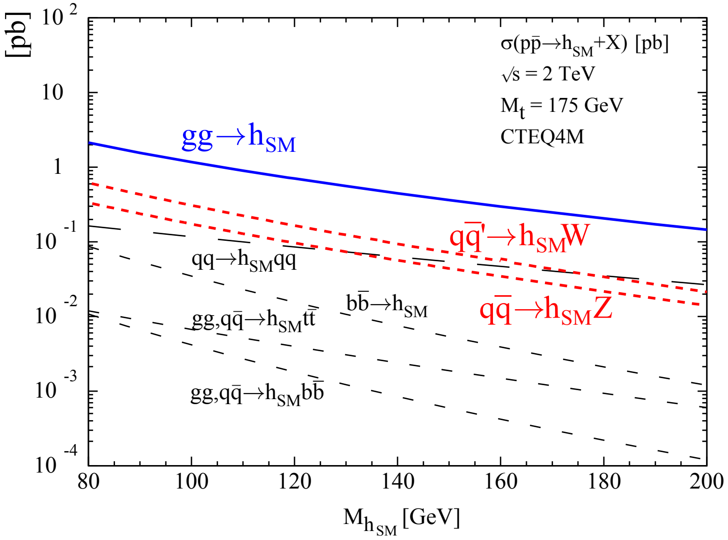


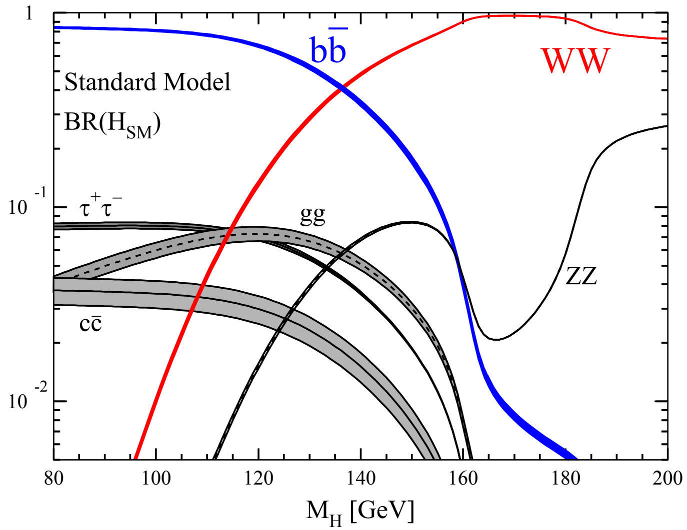
e^+	E_T = 73 GeV
e^-	E_T = 56 GeV
Jet 1	E_T = 35 GeV
Jet 2	E_T = 34 GeV
MET	E_T = 43 GeV

$M(e^+e^-)$ = 118 GeV

- 800 $t\bar{t}$ events with *b*-tagging are expected with 2 fb^{-1}
- Expect preliminary $\sigma_{t\bar{t}}$ and M_{top} by Spring 2003

Higgs at the Tevatron





Low-mass SM Higgs (≲ 130GeV/c²)

$q\bar{q}' \to Wh \to \ell\nu b\bar{b}$

$q\bar{q} \to Zh \to \ell^+\ell^- b\bar{b},\ \nu\bar{\nu} b\bar{b}$

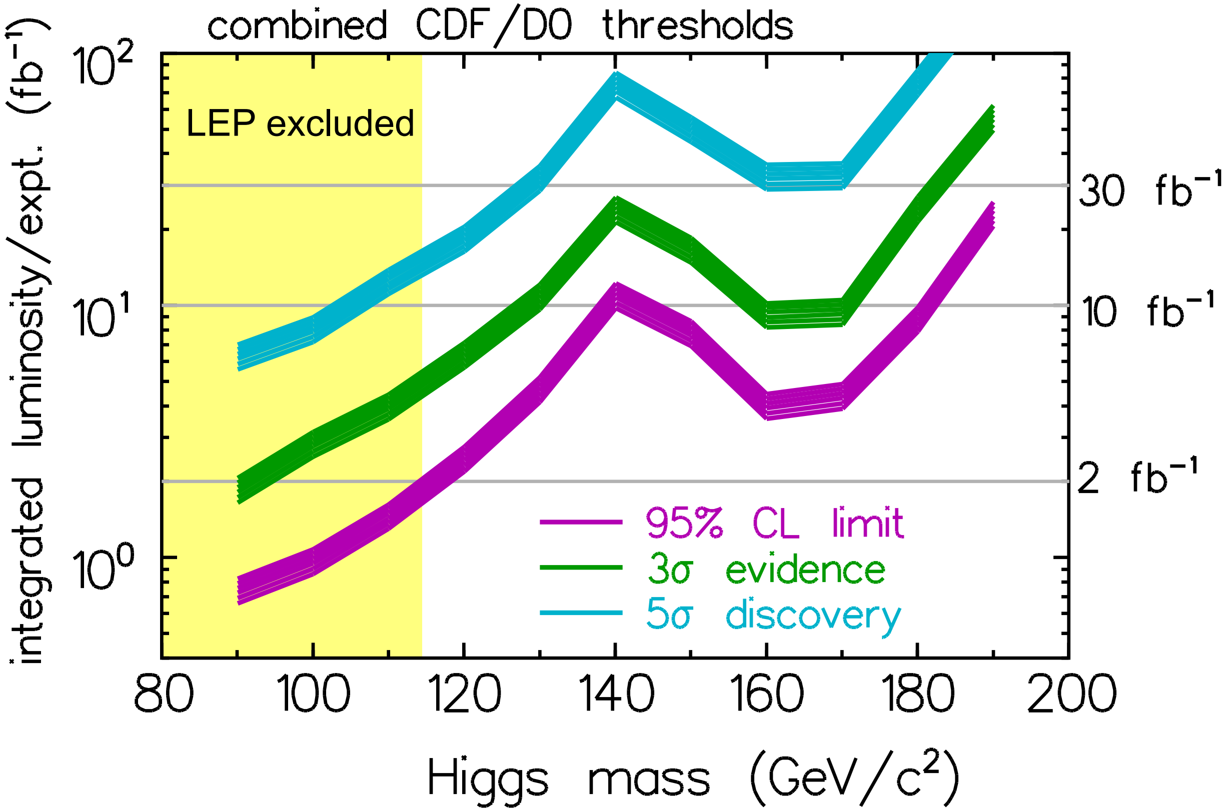
High-mass SM Higgs (130GeV/c² ~ 190GeV/c²)

$gg \to h \to W^*W^* \to \ell^+\ell^-\nu\bar{\nu}$

$q\bar{q}' \to Wh \to \ell^\pm\nu W^*W^* \to \ell^\pm\nu\ell^\pm\nu\, jj$

$q\bar{q} \to Zh \to \ell^\pm\ell^\mp W^*W^* \to \ell^\pm\ell^\mp\ell^\pm\nu\, jj$

Higgs at the Tevatron (2)



$2\ fb^{-1}$:
exclude M_h = 115 GeV/c^2, if not there

$5\ fb^{-1}$:
3σ signal for M_h = 115 GeV/c^2

$10\ fb^{-1}$:
3σ signal for M_h = 115 ~ 125, 155 ~ 175 GeV/c^2

- Sensitivity reevaluation in progress using fine-tuned full detector simulation

Top / Electroweak Projections

- $\sqrt{s}$ = 1.96TeV

  $\sigma(W)$, $\sigma(Z)$ ~ 10% higher

  $\sigma(t\bar{t})$ ~ 30% higher

- With 2 fb^{-1} (Run 2a)

  ΔM_W ~ 30 MeV/c^2

  $\Delta M_{top} \lesssim 3$ GeV/c^2

  $\Rightarrow \Delta(\log M_h) \sim \log 1.6$

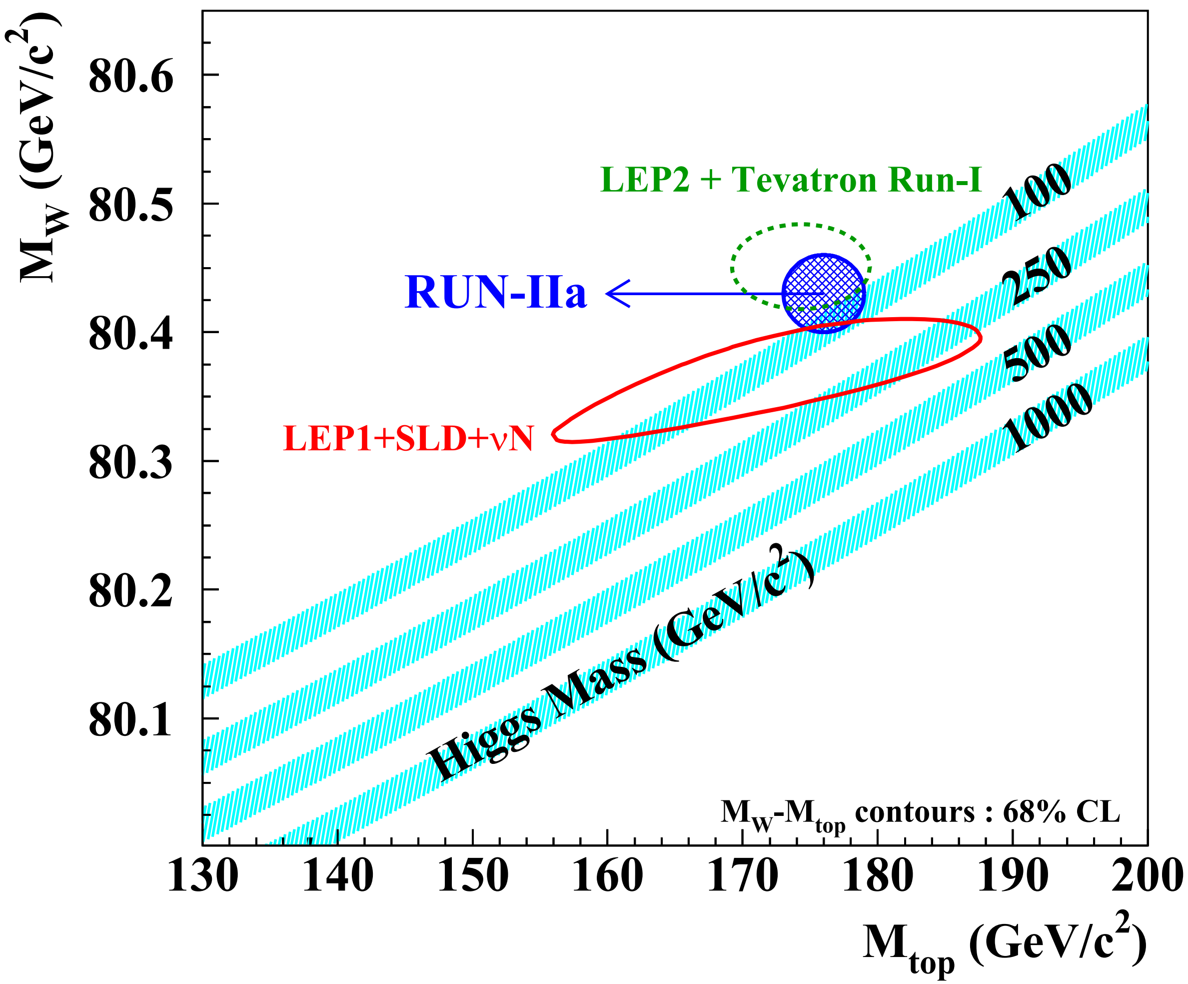
  $(1/1.6\, M_h < M_h < 1.6 M_h)$

- With 10 fb^{-1}

  ΔM_W ~ 20 MeV/c^2

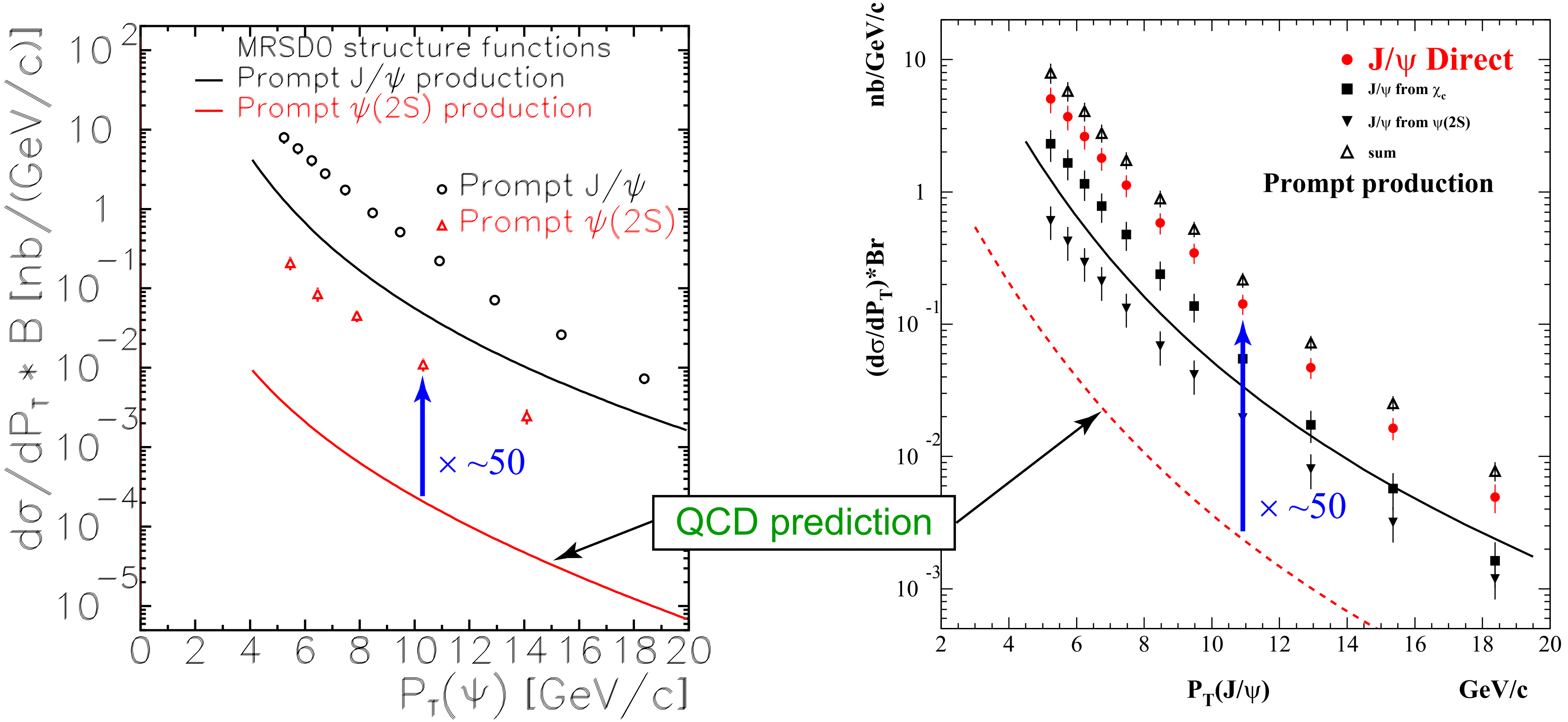
  $\Delta M_{top} \lesssim 2$ GeV/c^2

  $\Rightarrow \Delta(\log M_h) \sim \log 1.3$



- From Run I Results - Direct J/ψ Production

- Observed large excess of direct production of J/ψ and $\psi(2S)$ compared with QCD prediction with color singlet model(CSM).



CDF Collaboration, Phys. Rev. Lett. 79 (1997) 572., Phys. Rev. Lett. 79 (1997) 578.

- From Run I Results -

W + heavy-flavor jets

- Excess of W + 2,3 jet events compared with SM

One of these was tagged by both
- displaced vertex tag (SECVTX)
- soft lepton tag (SLT).

Source	$W+1$ jet	W+2jet	W+3jet	$W+\geq 4$ jet
SECVTX mistags in events with SLT tags	0.28 ± 0.03	0.09 ± 0.01	0.07 ± 0.01	0.02 ± 0.00
Non-W	0.57 ± 0.05	0.13 ± 0.03	0.00 ± 0.00	0.00 ± 0.00
WW,WZ,ZZ	0.02 ± 0.02	0.13 ± 0.06	0.01 ± 0.01	0.00 ± 0.00
Single top	0.12 ± 0.04	0.24 ± 0.05	0.07 ± 0.02	0.02 ± 0.00
Wc	0.88 ± 0.29	0.24 ± 0.14	0.14 ± 0.10	0.00 ± 0.00
$Wc\bar{c}$	0.41 ± 0.13	0.25 ± 0.09	0.13 ± 0.06	0.00 ± 0.00
$Wb\bar{b}$	1.58 ± 0.33	1.07 ± 0.26	0.19 ± 0.09	0.01 ± 0.00
$Z\to\tau\tau$	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Zc	0.01 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
$Zc\bar{c}$	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.00 ± 0.00
$Zb\bar{b}$	0.08 ± 0.02	0.05 ± 0.02	0.02 ± 0.01	0.00 ± 0.00
$t\bar{t}$	0.04 ± 0.02	0.48 ± 0.19	1.08 ± 0.40	1.42 ± 0.49
SM prediction (supertag)	4.00 ± 0.50	2.69 ± 0.41	1.71 ± 0.40	1.47 ± 0.51
Data (supertag)	1	8	5	2

4.4 ± 0.6

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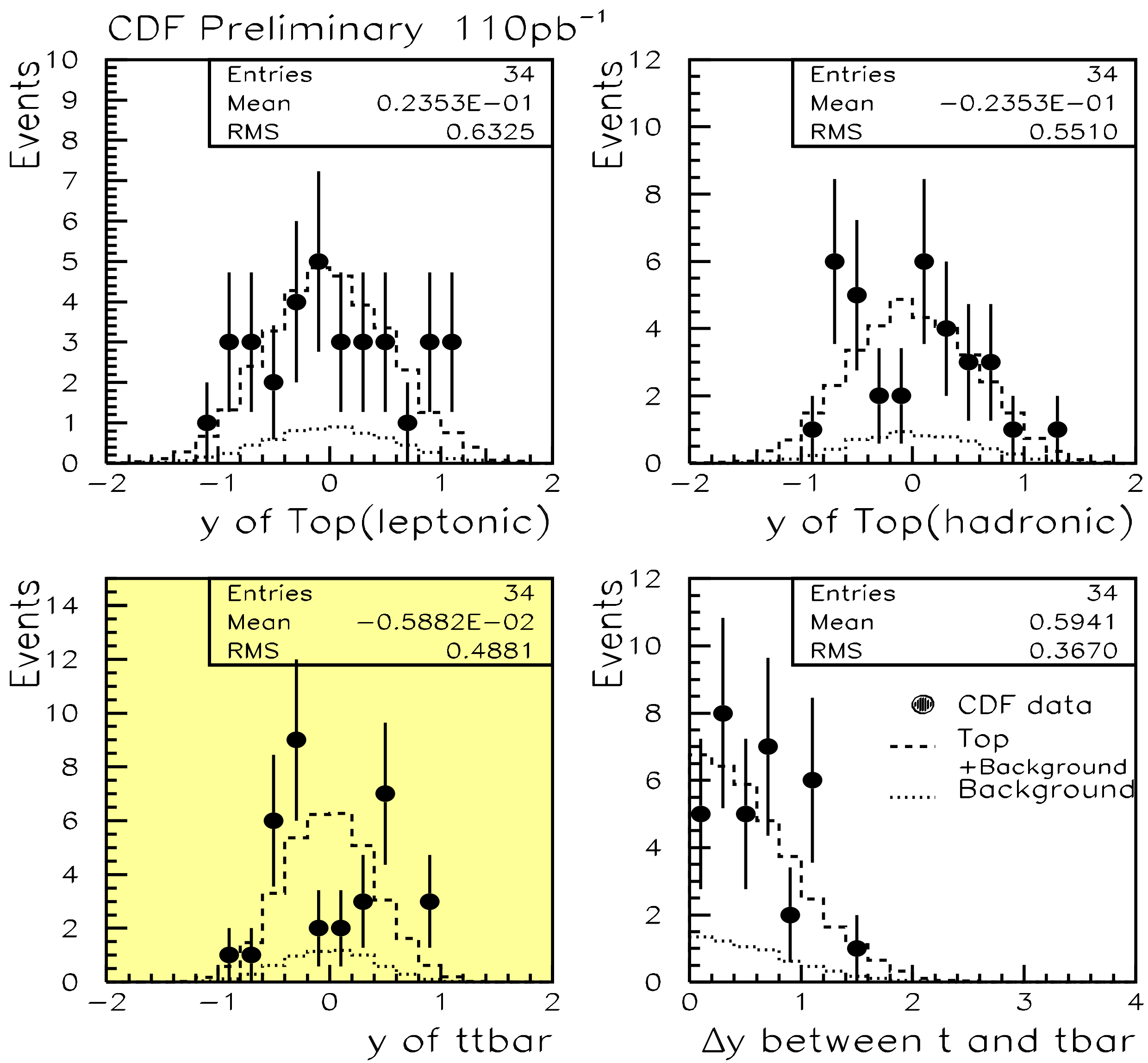
Need investigation with high-statistics data in Run II

CDF Collaboration, Phys. Rev. D65 (2002) 052007

- From Run I Results - Rapidity Distribution of $t\bar{t}$ Pair



Tevatron Plan and Luminosity Prospects

Run 2a

2003

- One month shutdown from January 13 $\rightarrow$ recovered on February 10
  - Increase C0 aperture
  - Others (dampers, MI, vacuum, etc.)
- During 2003
  - Complete Recycler work
  - Integrate Recycler into operation
  - Expect a delivered integrated luminosity of ~300 pb^{-1}

Run 2a goal

- Typical peak luminosity of $8 \times 10^{31}\ cm^{-2}s^{-1}$
- Integrated luminosity of 2 fb^{-1} over 2 ~ 3 year period

Tevatron Plan and Luminosity Prospects (2)

After 2 fb^{-1} (Run 2b)

- Increase anti-proton intensity
  - More protons on target
  - Better collection and transfer efficiency
- Peak luminosity up to 4 x 10^{32} $cm^{-2}s^{-1}$
- Silicon detector replacement at CDF and D0
  (Japan group is contributing to Run 2b silicon detector (SVXII-b) at CDF)
- Integrated luminosity of 6.5 ~ 11 fb^{-1} during ~4-year running (~2008)

Luminosity Prospects (fb^{-1})

FY	base	stretch
2002	0.08	0.08
2003	0.2	0.32
2004	0.4	0.6
2005	1.0	1.5
2006	1.5	2.5
2007	1.5	3.0
2008	1.5	3.0
Total	6.5	11.0

Summary

- Fermilab accelerators and collider detectors were successfully upgraded. Run 2 started in March 2001.
- Collider detectors are working well.
- We are accumulating physics data of $p\bar{p}$ collisions. Data analyses are also in progress. Some preliminary results were presented.
  The updated results will be shown at the upcoming high energy conferences.
- Luminosity of Tevatron is being improved. Hopefully, integrated luminosity of ~ 300 pb^{-1} in 2003, 2 fb^{-1} in 2 ~ 3 years, 6.5 ~ 11 fb^{-1} in ~2008.

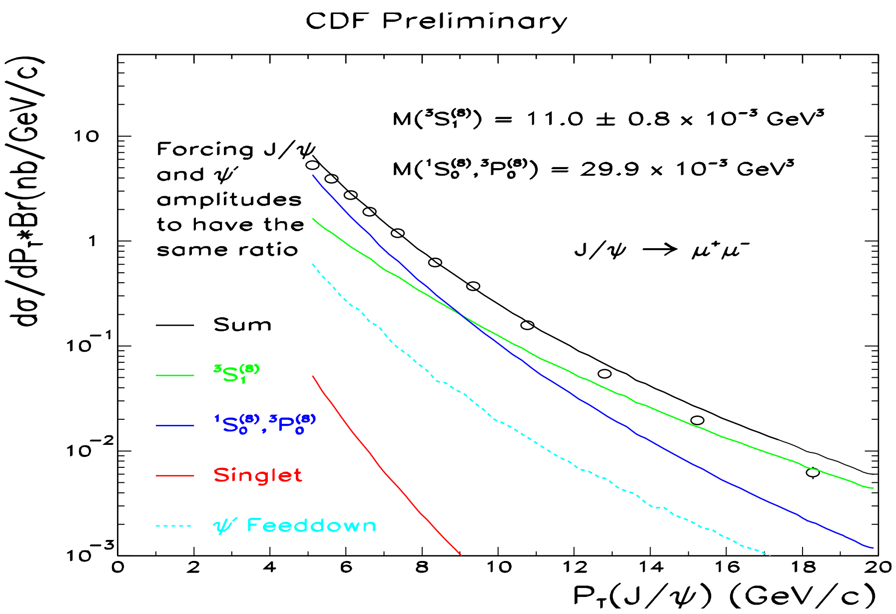
Backup Slides

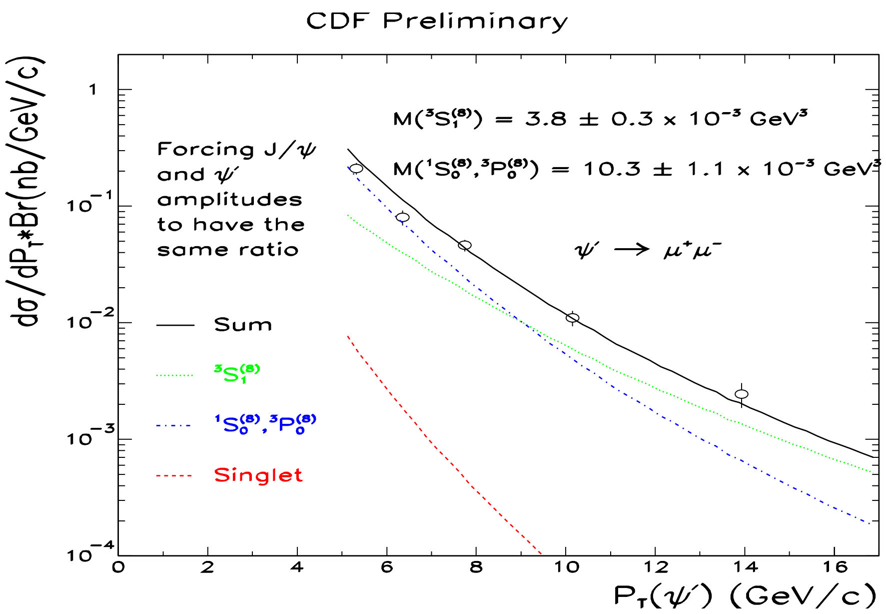
Tevatron Parameters and Performance

Parameter	Run Ib	Now (Nov. 2002)	Run 2a Goals	unit
# of bunches	6x6	36x36	36x36	
Protons/bunch	230	200	270	10^9
Antiprotons/bunch	55	26	30	10^9
Total Antiprotons	330	900	1080	10^9
Peak Pbar production rate	60	130	200	10^9/hour
Proton emittance	23	20	20	π mm-mr
Pbar emittance	13	18	15	π mm-mr
Beam energy	900	980	1000	GeV
Bunch length (proton, rms)	0.6	0.61	0.37	m
Bunch length (pbar, rms)	0.6	0.54	0.37	m
Typical luminosity	0.16	3.2	8.1	$10^{31}cm^{-2}s^{-1}$
Integrated luminosity	3.2	5	16	pb^{-1}/week

- From Run I Results - Direct J/ψ Production (2)

- Inclusion of the color octet model seems to fit the spectrum, but . . .



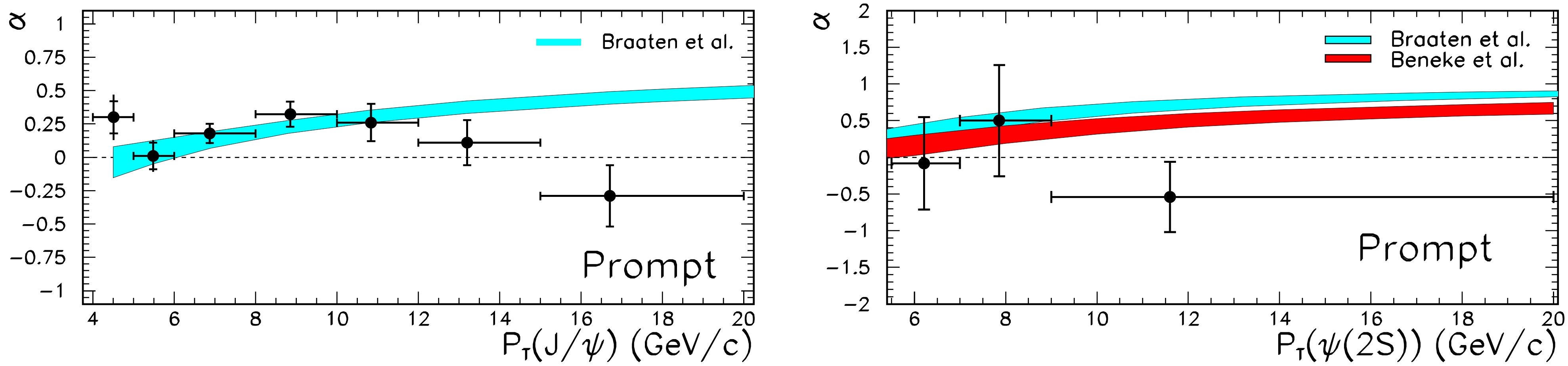


M. Beneke and M. Krämer, Phys. Rev. D55 (1997) R5269

- From Run I Results -

Direct J/ψ Production (3)

- Prediction of polarization disagrees with measurements at high-p_T.



CDF Collaboration, Phys. Rev. Lett. 85 (2000) 2886.